Martin County shore Protection Project

1996 Project Performance

by

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C2000-012

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1.0 INTRODUCTION

1.1 Overview

This report documents the analyses and results of the pre- and post-fill monitoring surveys of the 1996 Martin County, Florida, Shore Protection Project (termed Martin County SPP hereafter). The monitoring of the project consisted of pre- and post-construction beach and borrow area surveys, post-construction beach sediment sampling, and aerial photography. These survey data were collected and analyzed to fulfill the monitoring requirements outlined in the *Martin County, Florida, Shore Protection Project, Beach Performance Monitoring Plan* (USACE 1995).

1.2 Project Authorization

The Martin County SPP was authorized by the Water Resource Development Act of 1990 (Public Law 101-640). The project, as described in the *Martin County, Florida, Shore Protection Project General Design Memorandum* (USACE 1994), provides for 1) a protective beach berm and storm dune along four miles of Hutchinson Island, Florida, 2) periodic nourishment of the restored beach and such adjacent shoreline as may be needed and justified for the life of the project (note that federal participation expires in 2045), and 3) extensive multiyear beach performance monitoring.

1.3 Permit Requirements

The *Martin County, Florida, Shore Protection Project, Beach Performance Monitoring Plan* (USACE 1995) delineates the monitoring requirements for the beach fill project. The monitoring for the project has been a cooperative effort between the Jacksonville District; Martin County; Florida Department of Environmental Protection (FDEP), Bureau of Beaches and Coastal Systems and U.S. Fish and Wildlife Service. Appendix A contains a copy of the Beach Performance Monitoring Plan (USACE 1995) and a table summarizing the monitoring requirements and the time frequency of each requirement. Requirements tabulated are broader than those specified by FDEP permit No. DBS9A0306 MI in an effort to comply with all other agencies' requirements. The table has been updated from that presented in the Beach Performance Monitoring Plan to incorporate dates when requirements were accomplished and changes in requirements.

1.4 Project Description and History

The U.S. Army Corps of Engineers, Jacksonville District (Jacksonville District) awarded the Martin County SPP construction contract to Great Lakes Dredge and Dock Company in October 1995.

Construction of the project began December 13, 1995 and ended April 10, 1996 with the placement of approximately 1,340,000 cubic yards (cy) of beach quality sand (Rick McMillen, USACE — personal communication). The project extended about four miles from FDEP profile R-1 at the Martin County/St. Lucie County line to FDEP profile R-25 in Martin County. A 90-foot wide beach berm at an elevation of +9.1 ft above mean low water (MLW) was constructed. This construction berm consisted of a 35-ft wide authorized design berm, plus advance nourishment. The construction berm extended from FDEP profile R-2 south to profile R-24, with tapers continuing approximately 900 ft north and south to profiles R-1 and R-25. In addition to the beach berm, the authorized storm dune feature, 20-ft wide at elevation +13.6 ft MLW, was also constructed. The newly constructed dune, along with vegetation, extended from FDEP profile R-1 south to profile R-25. The borrow area was located approximately 1.2 miles offshore the southern region of the project area. Figure 1 illustrates the locations of the FDEP monuments, project area, north and south control areas, and borrow area.

The Martin County shoreline was battered by several storm events since commencement of project construction. The first major storm struck during project construction between March 11-13, 1996 when three-quarters of the project – from profile R-7 to profile R-25 – was complete. The contractor restored some of the previously constructed area of the project affected by the storm between profiles R-20 and R-25. The fall and winter seasons following completion of the project were characterized by a high amount of strong northeaster storms. Many of these storms affected the project area, especially the storms occurring between October 4-8 and November 15-18, 1996. The next major storm to impact the project area occurred between February 2-6, 1998. The project area was again battered by a series of storms in the latter summer of 1999. The passing of Hurricanes Dennis, Floyd and Irene caused more severe erosion to the project area.

1.5 Report Organization

The rest of this report is organized as follows. Chapter 2.0 reviews the available monitoring data and provides details of the beach and borrow area surveys such as survey date, description, and coverage. Chapter 3.0 documents and analyzes the effects of the beach nourishment project on beach profiles, shoreline positions, and beach volumes. Chapter 4.0 documents and analyzes the conditions ofthe borrow area over the monitoring period. Chapter 5.0 presents relevant wave climate data for storms affecting the beach nourishment project. Chapter 6.0 presents the summary and results of this study.

Appendix A contains the beach monitoring plan report and presents the survey monitoring schedule. Appendix B presents the survey monument coordinates for all beach profiles for all surveys.

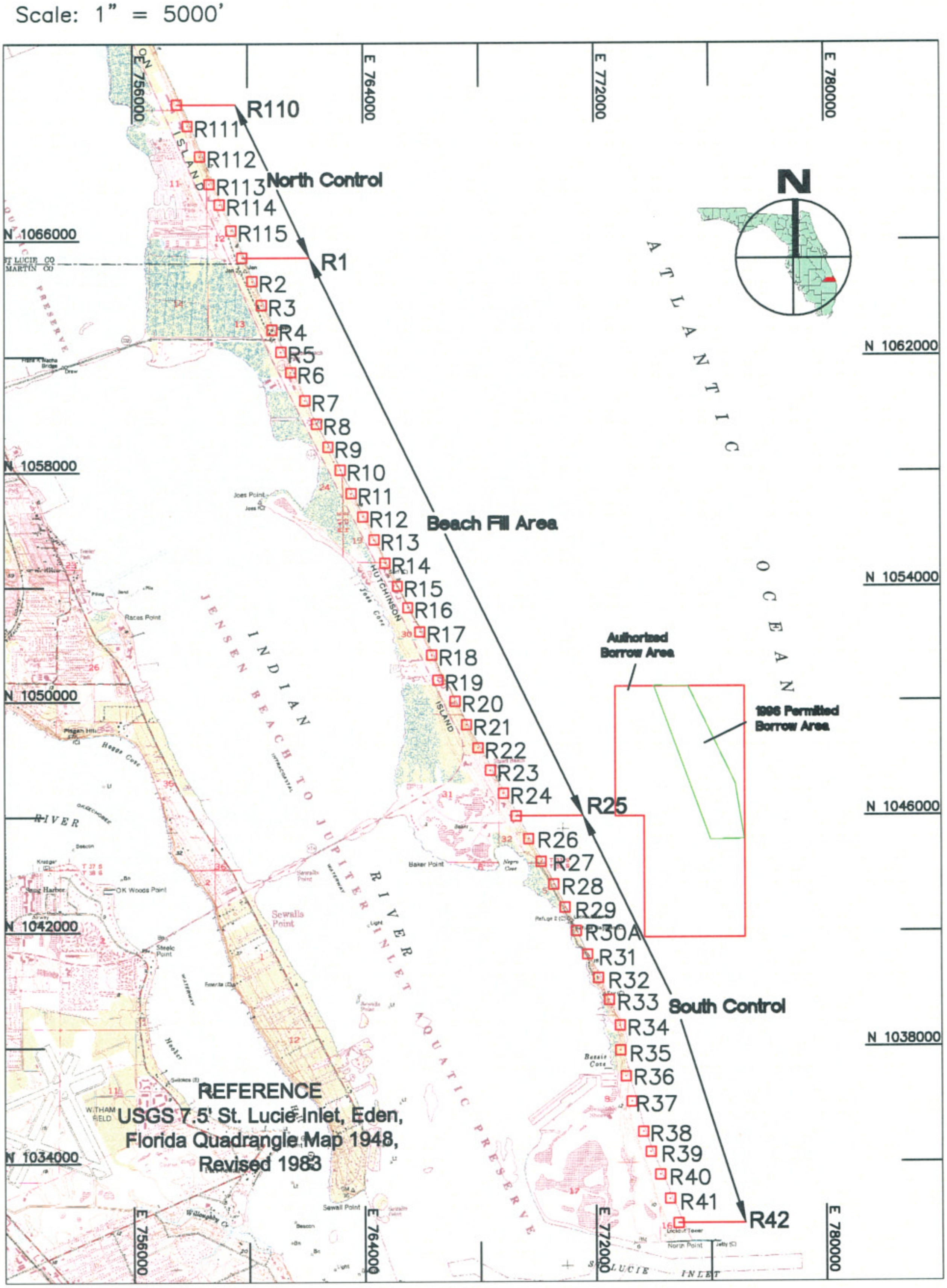

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Figure 1
Location Map for 1996
Beach Nourishment
Martin County, Florida

PROJECT	C2012
REVISION	
SHEET	
DATE	April 2000

Appendix C presents beach profile plots of all surveys, while Appendix D presents close-up beach profile plots of select surveys. Appendix E presents detailed information on shoreline positions and position changes for all pre- and post-fill beach profiles. Similarly, Appendix F presents detailed information on beach volumes for all pre- and post-fill profiles. Appendix G presents plots ofborrow area bathymetry for pre- and post-excavation conditions. This appendix also contains plots of bathymetric change over various comparison periods. Appendix H presents relevant wave climate data for storms affecting the beach nourishment project. Appendix I presents pictures of the beach nourishment project area taken before, during, and after project construction. Appendix J contains specifications used for aerial beach photography. Appendix K contains copies of pertinent correspondence between the FDEP and the Jacksonville District U.S. Army Corps of Engineers (USACE). Finally, Appendix L contains reports prepared by the USACE documenting the beach sediment analysis for post-construction conditions.

2.0 AVAILABLE MONITORING DATA

Beach profile surveys, borrow area bathymetric surveys, sand sampling surveys and aerial photography were conducted before and after project construction to monitor project performance. Appendix A presents the overall monitoring schedule and scope developed by the USACE.

The beach surveys document conditions in the project area (R-1 to R-25 in Martin County), a north control area (R-110 to R-115 in St. Lucie County), and a south control area (R-26 to R-42 in Martin County). The length of the project area is 21,626 ft (4 miles), the length of the north control area is 5,246 ft (1 mile), and the length of the south control area is 14,876 ft (3 miles). The beach surveys were nominally taken at approximate 1,000-ft longshore intervals. Table 1 provides a summary of each survey month and year, the survey designation, a survey description corresponding to each survey's relation to the project's timeframe, and the FDEP profile lines that were surveyed. The Jacksonville District U.S. Army Corps of Engineers (USACE) completed all surveys except for the 4-year survey, which was conducted by Martin County. Appendix B presents the monument locations and profile azimuths for all surveys conducted by the USACE. All profile data were reduced into a form referenced to the latest monument locations to facilitate intercomparison. Table 2 provides a listing of the survey monuments locations and profile azimuths used in all further analyses in the present study.

Table 1 Beach Profile Survey Dates and Extents

Survey Month and Year	USACE Designation	Survey Description	Monuments Surveyed		
			North Control[1]	Project Area	South Control
November 1995	96-005	Pre-fill	R-110 to R-115	R-1 to R-25	R-26 to R-30
April 1996	96-126	Post-March '96 Storm	R-110 to R-115	R-1 to R-25	R-26 to R-42
June 1996	96-164	Immediate Post-fill	R-110 to R-115	R-1 to R-25	R-26 to R-42
December 1996	96-252	8-month Post-fill	R-110 to R-115	R-1 to R-25	R-26 to R-42
May 1997	97-135	1-year Post-fill	R-110 to R-115	R-1 to R-25	R-26 to R-42
May 1998	98-087	2-year Post-fill	R-110 to R-115	R-1 to R-25	R-26 to R-42
May 1999	99-223	3-year Post-fill	R-110 to R-115	R-1 to R-25	R-26 to R-42
December 1999	9912[2]	4-year Post-fill	R-114 to R-115	R-1 to R-25	R-26 to R-27

[1]Profiles in St. Lucie County

[2]Survey conducted by Martin County

The USACE also surveyed the borrow area before and after project construction. These surveys document pre-fill, immediate post-fill, one-year post-fill, two-year post-fill, three-year post-fill, and four-year post-fill conditions (Table 3).

Table 2 Survey Monument Coordinates and Profile Azimuths				
	Monument	Easting (Feet)	Northing (Feet)	Azimuth (Degrees N)
North Control	R-110	757565.00	1070699.54	70
	R-111	757929.43	1069960.50	70
	R-112	758356.12	1068913.94	70
	R-113	758680.26	1067958.95	70
	R-114	759038.60	1067251.89	70
	R-115	759439.98	1066353.42	70
Project Area	R-1	759814.46	1065411.91	69
	R-2	760160.09	1064598.95	69
	R-3	760483.41	1063773.65	70
	R-4	760848.43	1062928.38	69
	R-5	761156.34	1062163.28	69
	R-6	761493.82	1061458.44	69
	R-7	761981.57	1060488.00	69
	R-8	762379.93	1059681.21	69
	R-9	762777.67	1058873.72	69
	R-10	763197.70	1058079.26	69
	R-11	763568.64	1057258.05	69
	R-12	763971.96	1056451.68	69
	R-13	764353.47	1055648.89	69
	R-14	764739.27	1054838.56	69
	R-15	765164.71	1054031.33	69
	R-16	765527.19	1053279.80	69
	R-17	765950.64	1052428.14	69
	R-18	766359.18	1051609.27	69
	R-19	766568.31	1050738.62	69
	R-20	767154.38	1049994.63	69
	R-21	767552.03	1049187.32	69
	R-22	767949.80	1048380.05	69
	R-23	768368.91	1047593.65	69
	R-24	768818.02	1046803.45	69
	R-25	769254.30	1046016.09	69
South Control	R-26	769689.25	1045228.37	69
	R-27	770125.01	1044440.26	69
	R-28	770560.94	1043652.15	69
	R-29	771077.23	1042676.24	69
	R-30	771334.47	1042032.72	69
	R-31	771719.80	1041216.37	69
	R-32	772091.72	1040401.14	69
	R-33	772464.54	1039638.71	69
	R-34	772868.58	1038759.23	69
	R-35	772853.99	1037891.38	69
	R-36	773041.18	1036989.28	69
	R-37	773247.75	1036112.61	69
South Control	R-38	773646.01	1035062.70	69
	R-39	773904.74	1034363.90	69
	R-40	774233.79	1033576.23	69
	R-41	774568.38	1032733.29	69
	R-42	774857.48	1031887.85	69

Table 3 Borrow Area Survey Identifier		
Survey Month and Year	USACE Designation	Survey Description
November 1995	96-005BA	Pre-fill
June 1996	96-164BA	Immediate Post-fill
May 1997	97-135BA	1-year Post-fill
May 1998	98-087BA	2-year Post-fill
May 1999	99-223BA	3-year Post-fill
April 2000	0004BA[2]	4-year Post-fill

Beach sand samples were taken at +10, 0, –10, and –15 ft NGVD elevations along eight beach profiles. These samples were taken in December 1996, May 1997, and June 1998 by the USACE to characterize post-fill, 1-year post-fill, and 2-year post-fill conditions. A detailed analysis of the sediment sampling is documented in Appendix L.

Aerial photography data was also collected to monitor the performance of the beach project. The aerial coverage extended from R-110 to R-115 in St. Lucie County and R-1 to R-42 in Martin County. The USACE monitoring schedule found in Appendix A lists the dates that aerial photography data was collected. Appendix J contains specifications used for the aerial beach photography.

For brevity, the immediate post-fill, the one-year post-fill, the two-year post-fill, the three-year post-fill, and the four-year post-fill beach and borrow surveys are referred to as the post-fill, the 1-year, the 2-year, the 3-year, and the 4-year beach and borrow surveys, hereafter.

3.0 ANALYSIS OF BEACH FILL AND ADJACENT CONTROL AREAS

This chapter presents analyses documenting the effects of beach nourishment on beach profiles, shoreline positions, and beach volumes in the project and monitoring areas.

3.1 Beach Profiles

3.1.1 Profile Adjustments

In several cases, all beach profile surveys (in time) for a particular transect location were not taken from the same basepoint (monument location). All profile data were organized referenced to common monument locations to facilitate survey intercomparison. Specifically, beach profile surveys taken from a monument different from the 1999 monument location were adjusted to either the May or December 1999 monument location as follows. All preceding surveys of profiles surveyed in December 1999 were adjusted to the December 1999 monument location. Some profiles were not surveyed in December 1999; consequently, all surveys of these profiles were adjusted to the May 1999 monument location. Table 4 lists the adjustment distances of monuments and surveys that were adjusted to match the 1999 monument location.

The monument-adjusted data were also plotted and reviewed for errors and inconsistencies. Where possible, causes of errors and inconsistencies were determined and corrections applied. Visual inspection of beach profiles revealed ambiguities in locations of backdune features for three profiles. These profiles were adjusted as follows. The post-fill survey for R-114 was adjusted 31 ft seaward, the post-fill survey for R-115 was adjusted 43 ft landward, and the pre-fill survey for R-20 was adjusted 85 ft seaward to match backdune features of these profiles with those of other surveys.

3.1.2 Profile Evolution

Appendix C contains beach profile comparison plots for each of the surveys listed in Table 1 for the entire monitored area (control and project areas). Appendix D contains close-up beach profile comparison plots for the pre-fill, post-fill, and 4-year surveys and the 1996 design template for the project area (R-1 through R-25). These plots also illustrate the location of the Corps Construction Line (CCL) and the Erosion Control Line (ECL). Table 5 lists the location of the CCL and ECL as a function of distance from the monument location.

Table 4
Survey Adjustments by Monument

Monument	Survey	Adjustment to May, 1999 (Feet)	Adjusment to December, 1999 (Feet)
R-112	96-005	-46.76	
	96-126	-46.76	
	96-164	-46.73	
	96-252	-46.76	
	97-135	-46.76	
R-11	96-164		5.11
R-14	98-087		-1.97
	99-223		-1.97
R-15	96-005		10.54
	96-126		10.54
	96-252		10.55
	97-135		10.55
	98-087		-1.8
	99-223		-1.8
R-16	96-164		8.58
R-17	96-005		-16.18
	96-126		-16.18
	96-252		-16.18
	97-135		-16.18
	98-087		-16.18
	99-223		-16.18
R-27	98-087		45
	99-223		45
R-29	96-164	-61.01	
R-34	96-126	-32.02	
	96-164	-32.75	
	96-252	-32.02	
	97-135	-32.02	
R-37	96-126	45.52	
	96-252	45.52	
	97-135	45.52	
R-41	96-126	-21.83	
	96-164	-23.18	
	96-252	-21.83	
	97-135	-21.83	

* a negative adjustment corresponds to a seaward shift,
a positive adjustment corresponds to a landward shift

Table 5 CCL and ECL Location from Monument			
Monument	Azimuth	CCL Distance From Monument (Feet)	ECL Distance From Monument (Feet)
R-1	69	-26.54	89
R-2	69	-23.93	74
R-3	70	-19.24	81
R-4	69	-25.72	74
R-5	69	25.86	130
R-6	69	-5.89	114
R-7	69	-17.27	86
R-8	69	-18.69	89
R-9	69	-15.08	83
R-10	69	-21.15	78
R-11	69	-24.35	78
R-12	69	-22.26	77
R-13	69	-23.87	92
R-14	69	-5.35	83
R-15	69	0.09	88
R-16	69	-16.65	89
R-17	69	-13.97	64
R-18	69	17.54	168
R-19	69	236.43	281
R-20	69	-1.01	90
R-21	69	-16	97
R-22	69	-3.91	126
R-23	69	-6.01	135
R-24	69	-1	113
R-25	69	-5.95	113

3.2 Shoreline Positions and Changes

Shoreline positions were analyzed for pre-fill, post-fill, 1-year, 3-year, 4-year, and 1996 construction template conditions. Appendix E contains tables and figures indicating mean high water (MHW) and MLW shoreline positions and shoreline position changes at all beach profile locations. Note that MHW for the project area is +1.8 ft NGVD and MLW is –1.1 ft NGVD.

Figures 2 and 3 present MHW and MLW shoreline position changes between survey dates on a profile-by-profile basis in the monitored area. These comparisons include the construction template to pre-fill, post-fill to pre-fill, 1-year to post-fill, 3-year to post-fill, and 4-year to post-fill conditions. Figure 4 illustrates the average MHW and MLW shoreline position in the project area for each survey. Significant features of shoreline position changes are discussed next.

3.2.1 Project Area

A comparison of post-fill (surveyed two months following project completion) to pre-fill shoreline locations indicates that the MHW and MLW shorelines in the project area, on average, advanced 105 ft and 94 ft, with construction of the project. MHW position change varied from +148 ft (R-19) to +27 ft (R-25) and MLW position change varied from +143 (R-17) to -3 ft (R-25). Note that '-' denotes shoreline retreat while '+' denotes shoreline advance.

A comparison of construction template to pre-fill conditions indicates that the MHW and MLW shorelines in the project area, on average, should have advanced 114 ft and 113 ft. Assuming that the contractor filled out the construction template during project construction, the difference between the post-fill and construction template conditions indicates that the beach, on average, eroded between the project construction date and the post-fill survey date. This trend is to be expected because the beach profile is immediately trying to adjust to a milder-sloped equilibrium shape from the steep-sloped construction shape.

One year after project construction, the MHW and MLW shorelines, on average, retreated 54 ft and 51 ft from their post-fill positions. MHW position change varied from -94 ft (R-12) to -8 ft (R-1) and MLW position change varied from -96 ft (R-12) to +7 ft (R-1). The MLW shoreline at R-1 was the only location experiencing accretion over this time interval. This behavior is consistent with expectation, since beach fill evolution theory for tapered fills predicts progressive accretion along the outer half of the taper (i.e., between R-1 and R-1.5 in the present case).

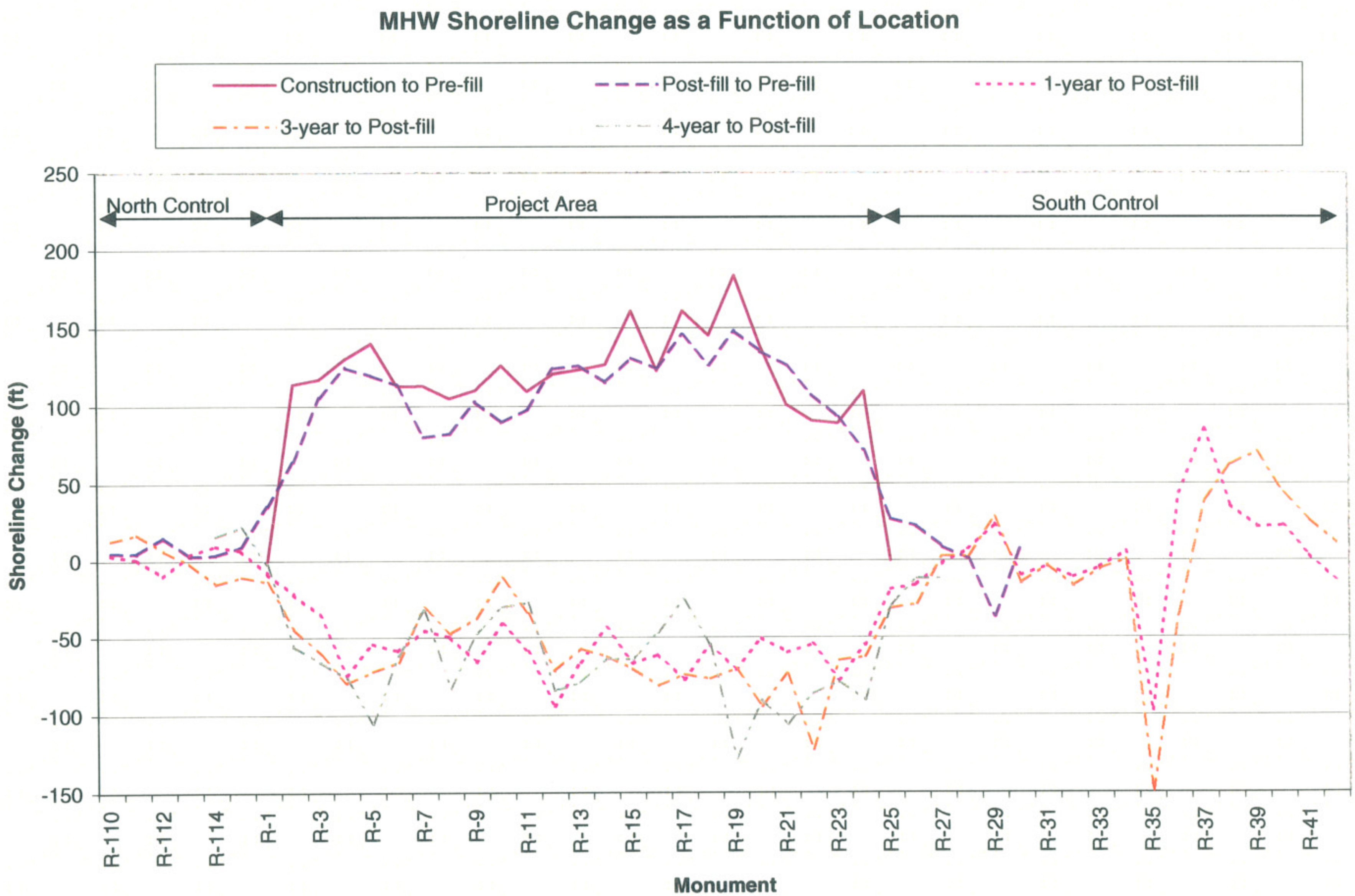


Figure 2 MHW Shoreline Change as a Function of Location

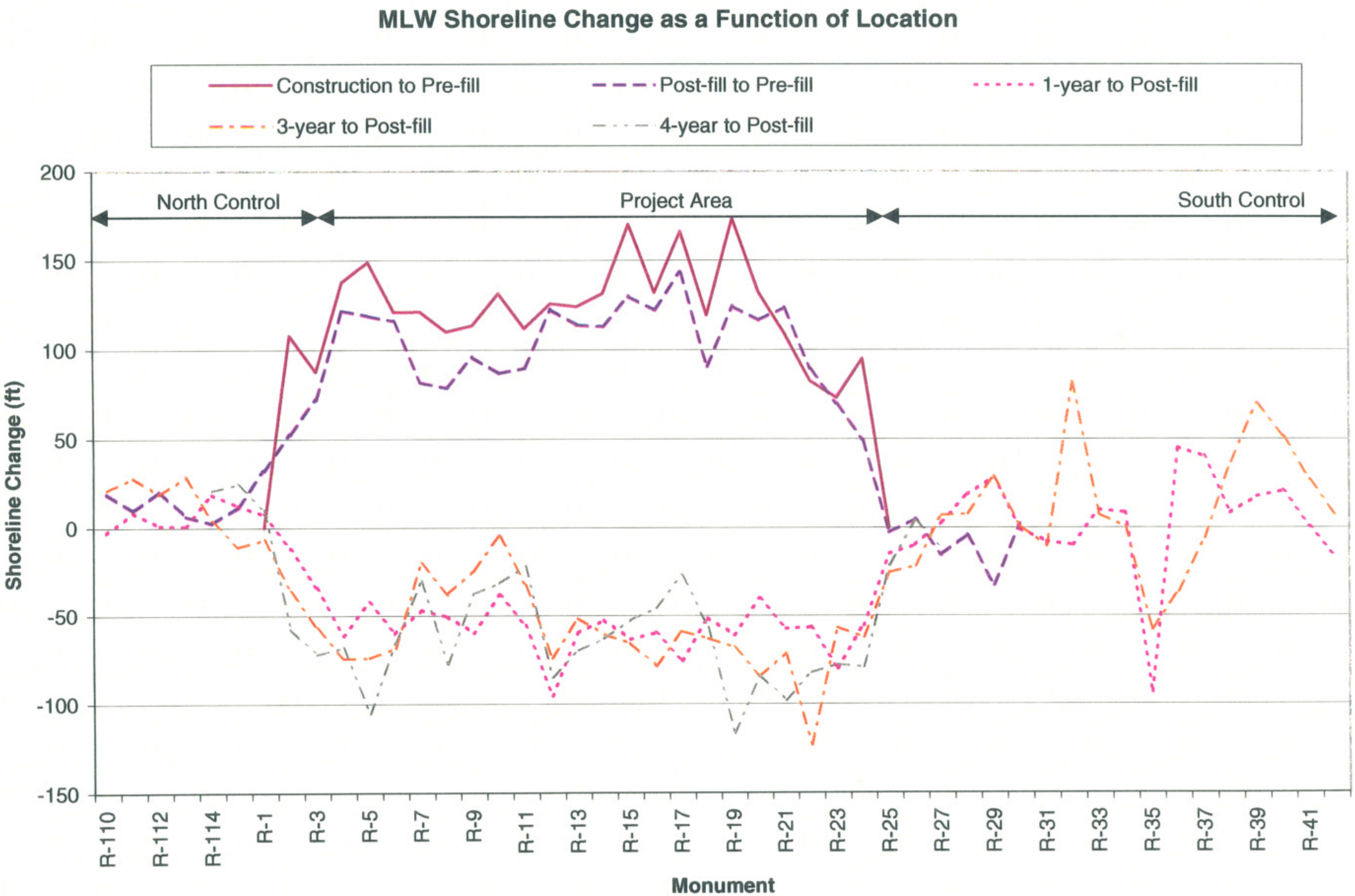


Figure 3 MLW Shoreline Change as a Function of Location

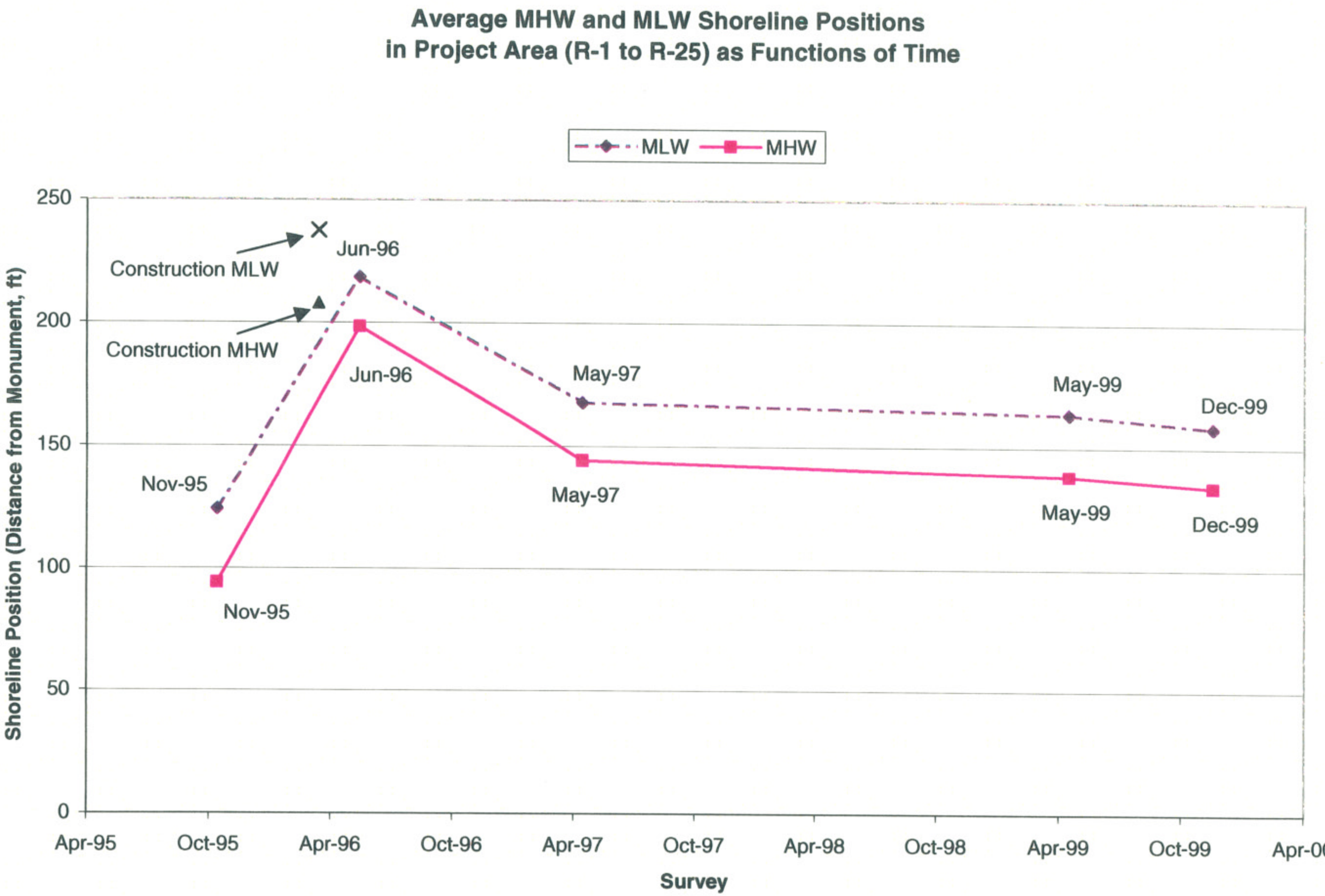


Figure 4 Average MHW and MLW Shoreline Positions in Project Area (R-1 to R-25) as Functions of Time

Three years following project construction, the MHW and MLW shorelines, on average, retreated 60 ft and 55 ft from their post-fill positions. MHW position change varied from -122 ft (R-22) to -14 ft (R-1) and MLW position change varied from -123 ft (R-22) to -7 ft (R-1).

Four year following project construction, the MHW and MLW shorelines, on average, retreated 65 ft and 61 ft from their post-fill locations. MHW position change varied from -128 ft (R-19) to -2 ft (R-1) and MLW position change varied from -117 ft (R-19) to +10 ft (R-1).

The MHW and MLW shorelines in the project area both display an erosional trend with completion of the project. At each survey after the post-fill survey, both the MHW and MLW shorelines are eroded from their previous positions. This trend for continuous retreat of the shoreline is consistent with the design of a beach nourishment project. The beach fill acts as a perturbation to the natural shoreline. Consequently, cross-shore equilibration and longshore dispersion transport processes cause the beach fill to lose sand as it equilibrates over time. Measurements indicate that in the first year after construction, the MHW and MLW shorelines eroded, on average, 54 ft and 51 ft; in the next three years, they only eroded, on average, another 11 and 10 ft. This trend is consistent with beach fill dispersion theory, which predicts that the rate of erosion is highest after the beach fill is first completed and then the rate of erosion progressively slows with time.

3.2.2 North Control Area

A comparison of post-fill (surveyed two months following project completion) to pre-fill shoreline locations indicates that the MHW and MLW shorelines advanced everywhere in the north control area. The MHW and MLW shorelines, on average, advanced 7 ft and 12 ft. MHW position change varied from +15 ft (R-112) to +3 ft (R-113) and MLW position change varied from +21 (R-112) to +3 ft (R-112).

One year after project construction, the MHW and MLW shorelines, on average, advanced 3 ft and 7 ft from their post-fill positions. MHW position change varied from +10 ft (R-114) to -10 ft (R-112) and MLW position change varied from +19 ft (R-114) to -3 ft (R-110).

Three years after project construction, the MHW and MLW shorelines, on average, advanced 2 ft and 15 ft from their post-fill positions. MHW position change varied from +17 ft (R-111) to -15 ft (R-114) and MLW position change varied from +29 ft (R-113) to -11 ft (R-115).

Four years after project construction, the MHW and MLW shorelines, on average, advanced 19 ft and 23 ft from the post-fill locations. Note that this comparison extends over profiles R-114 and R-115 only. MHW position change varied from +22 ft (R-115) to +16 ft (R-114) and MLW position change varied from +25 ft (R-115) to +21 ft (R-114).

A trend of slow accretion is evident in the north control area. Beach fill theory predicts that beaches north (and south) of the placement area should accrete due to dispersion of the beach fill. However, by one year after project construction, the north control area had only experienced MHW and MLW shoreline advancements, on average, of 3 ft and 7 ft from the post-fill positions. By four years, the MHW and MLW shorelines had advanced, on average, 19 ft and 23 ft from their post-fill positions; some or all of this advancement may be due to dispersion of the beach fill. Thus, the rapid erosion of the beach fill, primarily due to cross shore transport as shown in Section 3.3, is not accompanied by a comparable rate of rapid accretion in the control area.

3.2.3 South Control Area

To enable consistent comparisons with results of the north control area (which encompasses five profiles), the following discussion only addresses the northern-most five profiles (R-26 through R-30) of the south control area. MHW and MLW shoreline changes computed for all the profiles (R-26 through R-42) in the south control area are presented in Appendix E.

A comparison of post-fill (surveyed two months following project completion) to pre-fill shoreline locations indicates that, on average, the MHW shoreline advanced 1.0 ft while the MLW shoreline retreated 9 ft. MHW position change varied from +22 ft (R-26) to -36 ft (R-29) and MLW position change varied from +5 (R-26) to -33 ft (R-29).

One year after project construction, the MHW and MLW shorelines, on average, advanced 1 ft and 8 ft from their post-fill positions. MHW position change varied from +23 ft (R-29) to –16 ft (R-26) and MLW position change varied from +29 ft (R-29) to -10 ft (R-26).

Three years after project construction, the MHW shoreline retreated, on average, 2 ft, while the MLW shoreline advanced, on average, 5 ft from their post-fill positions. MHW position change varied from +28 ft (R-29) to -28 ft (R-26) and MLW position change varied from +29 ft (R-29) to -22 ft (R-26).

Four years after project construction, the MHW and MLW shorelines, on average, retreated 12 ft and 4 ft from their post-fill positions. Note that this comparison extends over profiles R-26 and R-27 only. MHW position change was -12 ft for both profiles while MLW change varied from +4 ft (R-26) to -11 ft (R-27).

No obvious trends are evident in the south control area. Beach fill theory predicts that beaches south (and north) of the placement area should accrete due to dispersion of the beach fill. Measurements indicate that one year after project construction, the MHW and MLW shorelines were advanced, on average, only 5 ft and 4 ft from their post-fill positions. Four years after project construction, the MHW and MLW shorelines had actually retreated, on average, 12 ft and 4 ft from their post-fill positions. Thus, this region does not appear to have ostensibly benefited from the beach fill; yet, it may be argued that in the absence of a beach fill project immediately to the north, more severe erosion than currently observed may have resulted in the south control area. Causes for aggravated erosion in the control area are not readily apparent – typical shoreline orientations in the south control area are fairly uniform and similar to those in project area. However, one difference does exist between the nearshore bottom characteristics in the project and south control areas – the project area has scattered, primarily offshore, hardbottom while the nearshore area is typically sandy and relatively free of hardbottom; in contrast, a nearshore benthic survey of a limited portion (between R-25 and R-27) of the south control area revealed the presence of a continuous band of hardbottom proximate to the shoreline in depths of 3-5 ft (Continental Shelf Associates, 2000). Presence of nearshore hardbottom may have some bearing on nearshore wave propagation and consequently beach and shoreline behavior. However, firm assertions on the apparent high erosion rate of the south control area cannot be made without a detailed morphological model for this area; such an endeavor is beyond the scope of the present study.

3.2.4 Beach Fill Evolution: Comparison with Model Predictions

This section presents a simplified analytical model commonly used to predict beach fill evolution during beach fill design for engineering (fill life, erosion rates, effects on adjacent beaches, etc.) and economic (project benefits — increase in storm damage protection, renourishment interval, etc.) purposes. This analytical solution for beach fill evolution has a beach fill diffusivity factor that must be calibrated to site-specific conditions. The monitoring data presented here lends an opportunity to calibrate and check the overall performance of this beach fill evolution analytical model.

Beach fill adjustment due to longshore sediment transport processes has been studied for about four decades; with some assumptions, the analysis is quite straightforward. On a time scale of years to decades, the beach profile shape is assumed to be invariant. However, the beach fill disrupts the natural shape of the shoreline. Following the theory first outlined by Pelnard-Considere (1956), a beach fill represents a perturbation or a planform anomaly to the local uninterrupted shoreline which, over time, is smoothed out by longshore sediment transport. The principal mechanism for sediment transport is the longshore current due to obliquely breaking waves. Sediment transport is essentially considered to be proportional to the longshore component of the breaking wave energy flux (e.g., Inman and Bagnold, 1963). Assuming spilling breakers, small breaking angles, and a profile that translates landward or seaward without change of form, a linearized approximation results in the following governing equation for planform evolution:

$$\frac{\partial y}{\partial t} = G\frac{\partial^2 y}{\partial t^2} \qquad (1)$$

where y is the cross shore position of the shoreline at time t, and x the alongshore distance. This is in the form of the well-known heat conduction equation with a number of possible analytical solutions; the boundary conditions (at the lateral ends) specify the particular solution. G, often known as the longshore diffusivity, governs the rate of evolution of the project. In this linearized treatment,

$$G = K\frac{H_0^{2.4}C_{g,0}^{1.2}g^{0.4}}{8(s-1)(1-p)C_{*}\kappa^{0.4}(h_{*}+B)}\left[\frac{\cos^{1.2}(\beta_0-\alpha_0)\cos 2(\beta_0-\alpha_{*})}{\cos(\beta_0-\alpha_{*})}\right], \qquad (2)$$

where K is an empirical nondimensional constant (–0.32), H the significant wave height, C_G the wave group velocity, g the acceleration due to gravity, s the specific gravity of sand (–2.65), p the sediment porosity (–0.35), C the wave velocity, κ the ratio of the breaking wave height to the breaking water depth (≈ 0.78), h_* the water depth of limiting sediment motion, B the height of the berm above the water level,β the shoreline azimuth, and α the direction of the waves. The subscripts 0 and * denote conditions in deep water and at the depth of limiting motion. Based on a survey of general site conditions, Dean (1990) suggests a value of G ~ 0.08 ft²/sec for the vicinity of the project area. However, given the uncertainties in specific site conditions — e.g., wave and water level climate over the time period of interest and local shoreline orientations — the G value typically functions as a calibration parameter in Equation 1.

The solution for the evolution of an initially rectangular beach fill is

$$y(x,t) = \frac{Y}{2}\left[erf\left(\frac{l}{4\sqrt{Gt}}(\frac{2x}{l}+1)\right) - erf\left(\frac{l}{4\sqrt{Gt}}(\frac{2x}{l}-1)\right)\right], \qquad (3)$$

where Y is the initial width of the planform anomaly (beach fill), l the project length, and erf the error function.

The average shoreline extension in the project area, obtained by comparing the construction template to the pre-fill conditions, was about 113 ft. Equation 3 was used to model the evolution of the beach fill shoreline using a range of G values from 0.05 to 6.0 ft^2/s. The root mean square (rms) error between the predicted and measured shoreline positions in the project area (the control areas were not considered in this analysis) for each survey date defined as

$$E = \sqrt{\frac{1}{I}\sum_{i}(y_{m,i} - y_{p,i})^2} \qquad (4)$$

was minimized to obtain the best fit G value for each survey date. $y_{m,i}$ and $y_{p,i}$ are the measured and predicted shoreline positions at each profile location i and I is the number of profile locations in the project area where data is available. The best-fit G values, presented in Table 6, are considerably higher than the recommended G value of 0.08 ft^2/s. As seen from this table, the longshore diffusivity G starts off with a relatively low value for the 2-month post-fill condition, increases to a very large value for the 12-month condition, and decreases to a relatively smaller value for the 36- and 42-month conditions. Note that multiple storm impacts which appear to have caused substantial cross shore transport in the area (see Section 3.3 and Chapter 5.0) during and following project construction may have resulted in the violation of the important assumption of uniform profile translation without change in form. This violation may be responsible for the high G values reported here.

Table 6
Best-Fit Longshore Diffusivity Values for Different Conditions

Survey	Time After Nourishment (Months)	Best-Fit G (ft^2/s)	RMS Error (ft)
96-126	2	0.3	4.0
97-135	12	5.1	4.2
99-223	36	2.2	5.0
9912	42	2.4	6.1

Measured and predicted 2-month, 12-month, 36-month, and 42-month shorelines are presented in Figures 5 through 8. The best-fit G values for the respective dates produce reasonable fits to measured shoreline changes.

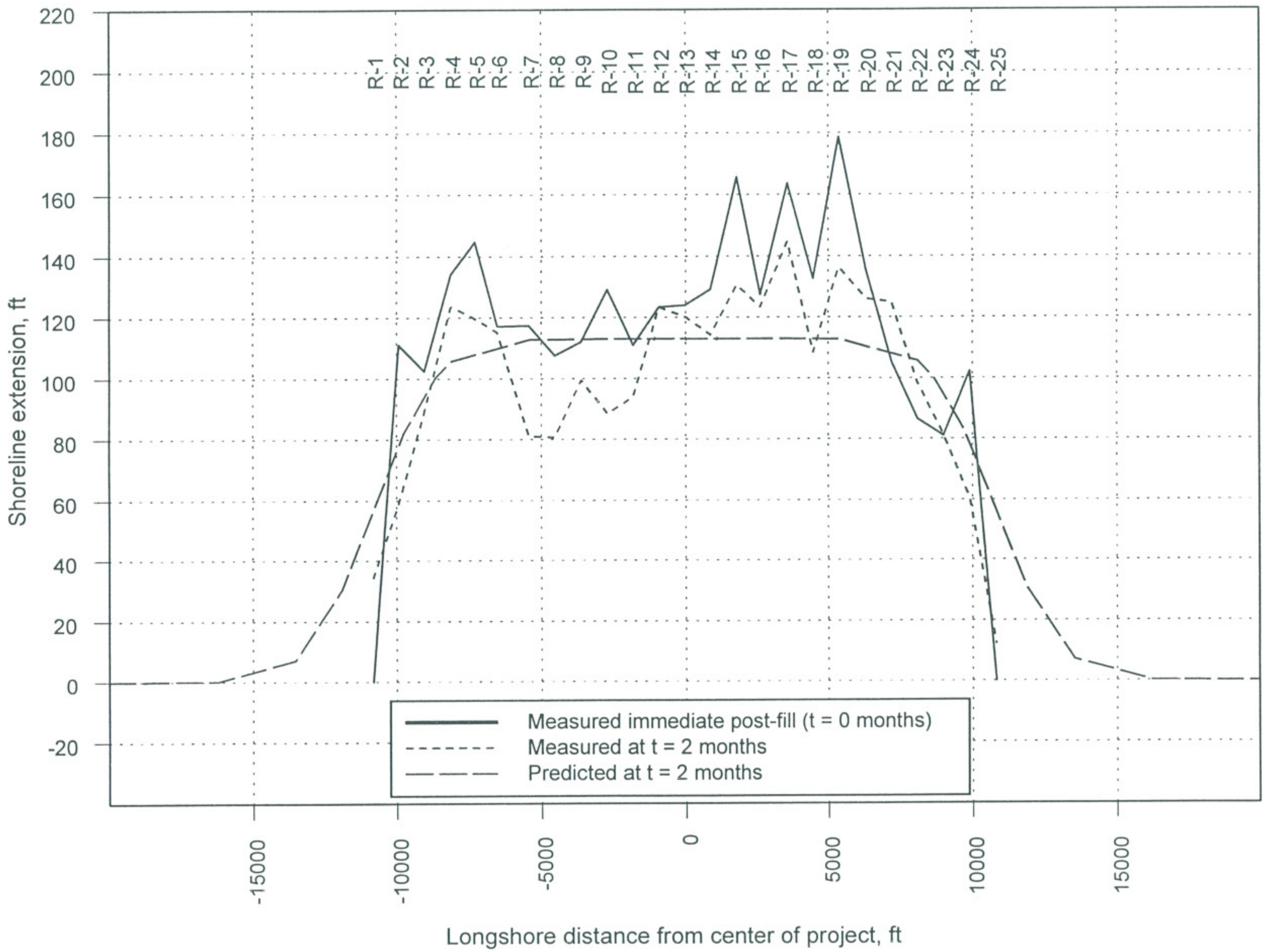


Figure 5 Two Months After Beach Nourishment: Measured and Predicted Best-Fit Shorelines

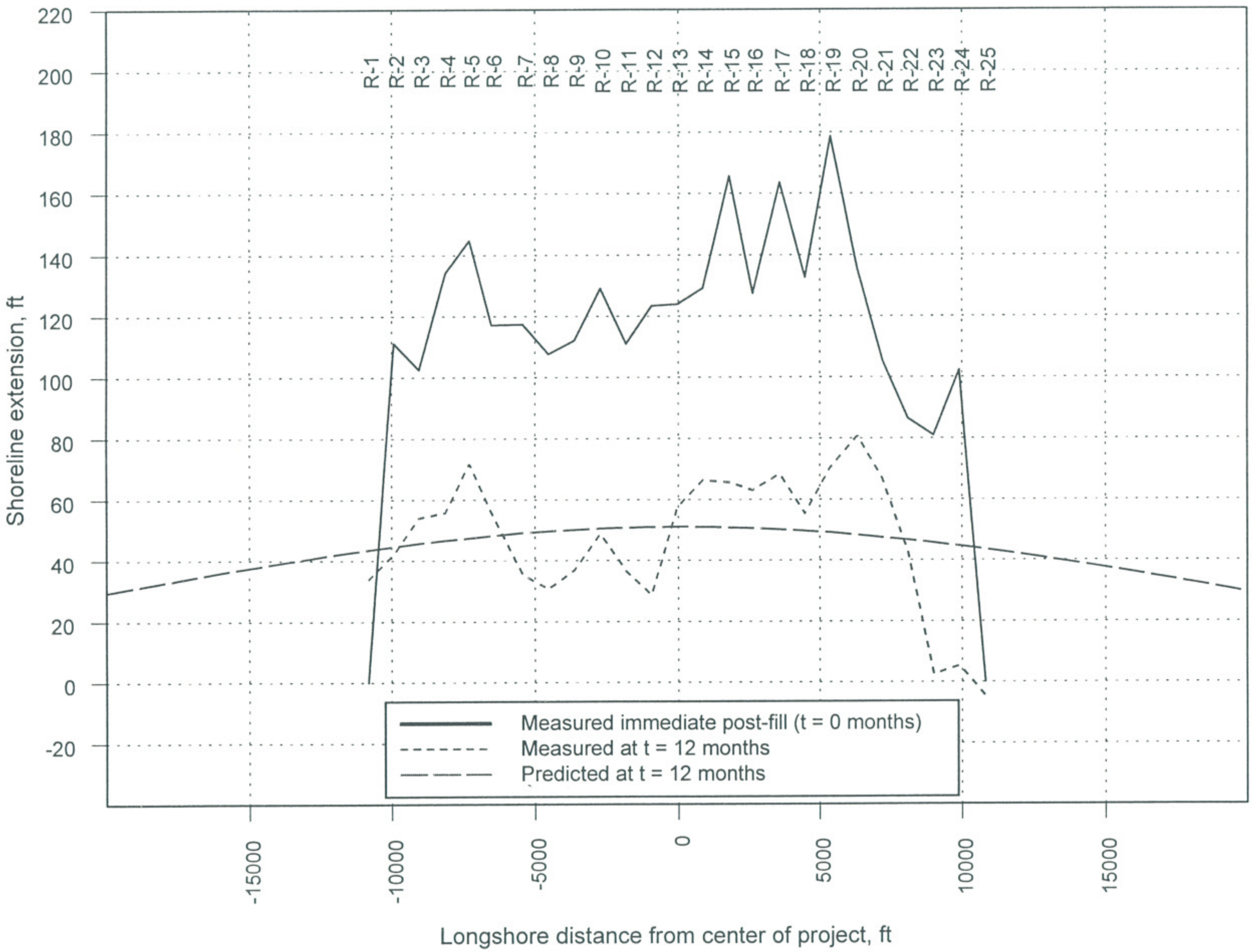


Figure 6 12 Months After Beach Nourishment: Measured and Predicted Best-Fit Shorelines

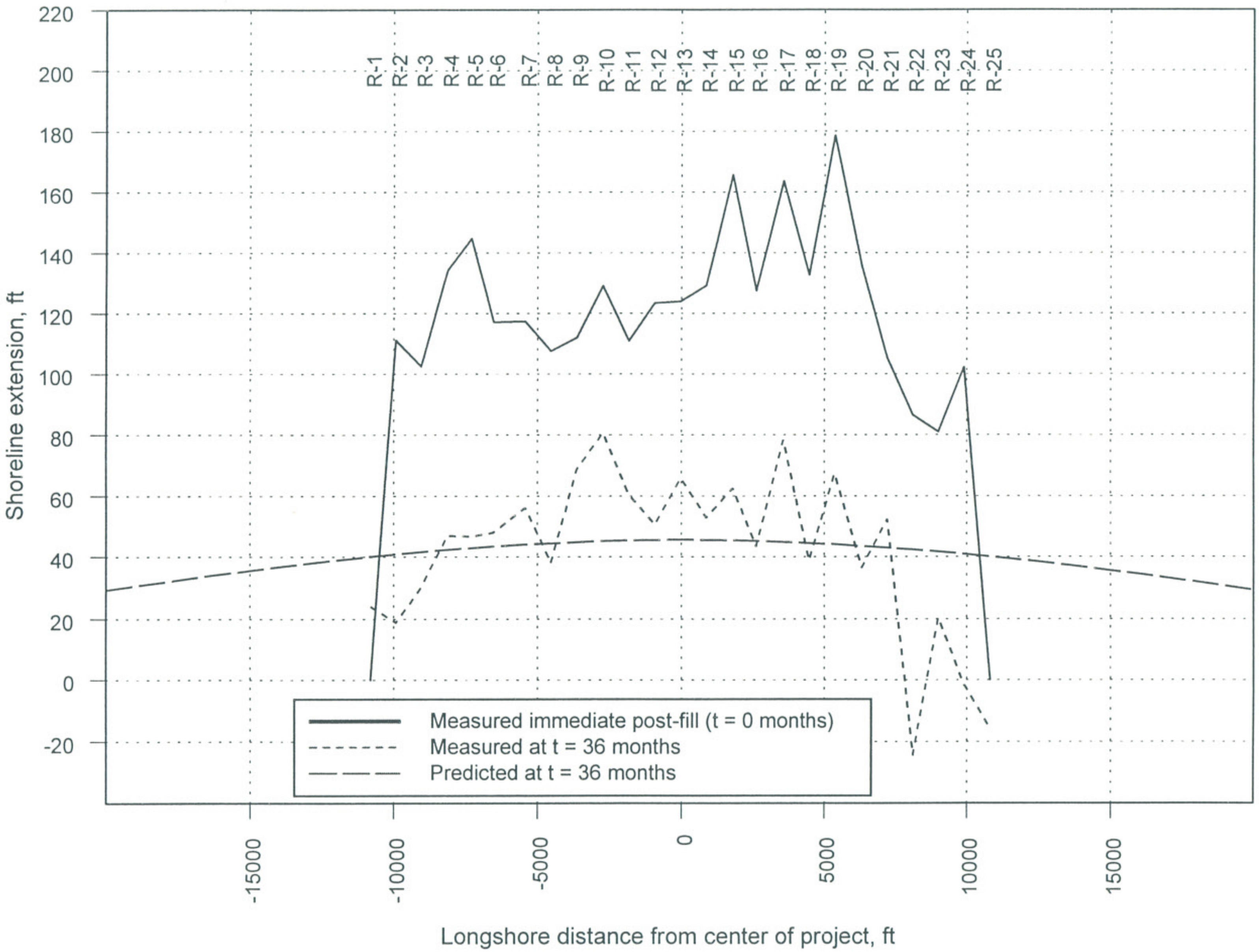


Figure 7 36 Months After Beach Nourishment: Measured and Predicted Best-Fit Shorelines

Figure 8 42 Months After Beach Nourishment: Measured and Predicted Best-Fit Shorelines

3.3 Beach Volumes and Changes

Beach volumes were computed for pre-fill, 1996 construction template, post-fill, 1-year, 3-year, and 4-year conditions. Beach volume changes were computed for the construction to pre-fill conditions, post- to pre-fill conditions, the 1-year to post-fill conditions, the 3-year to post-fill conditions, and the 4-year to post-fill conditions. Beach volumes and volume changes were calculated in four vertical compartments:

(1) between the CCL and MHW contours,

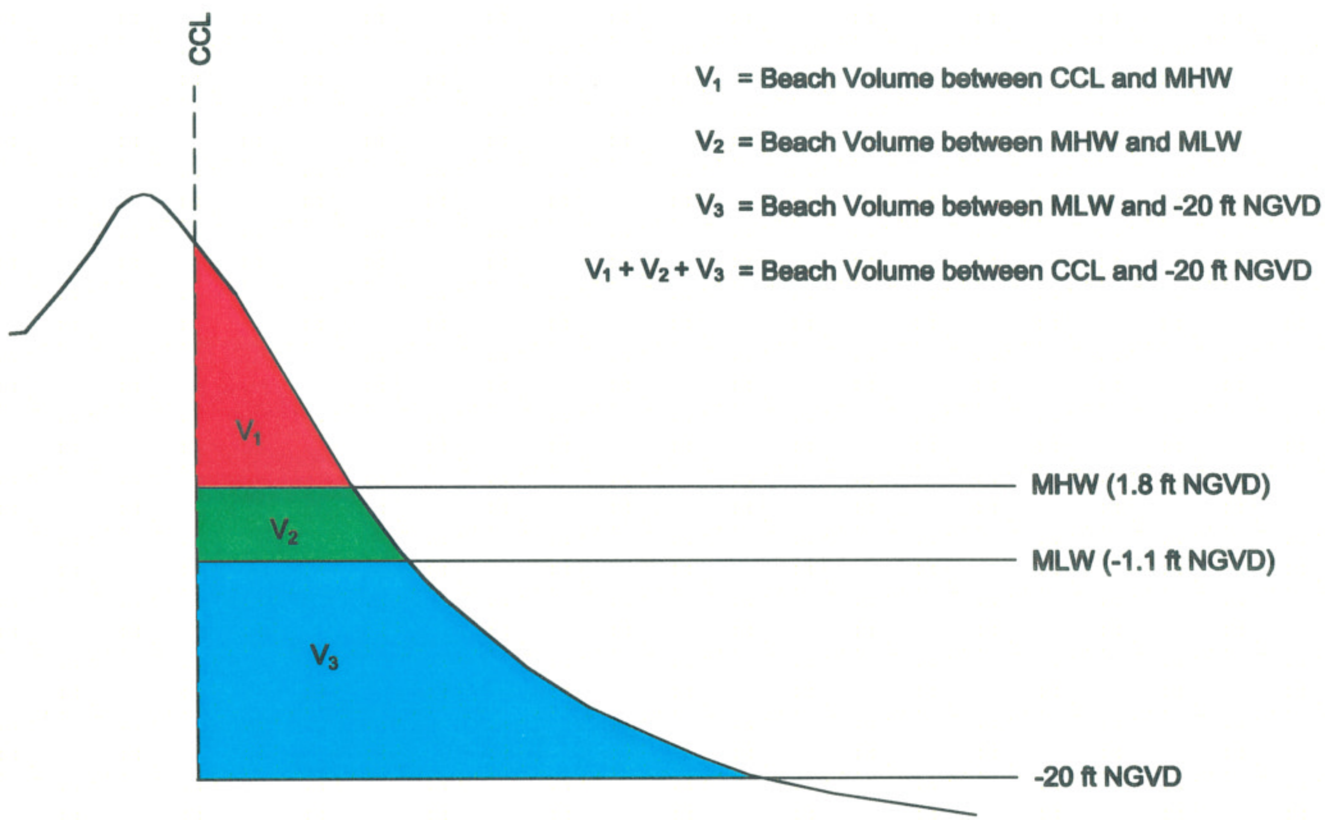
(2) between the MHW and MLW contours,

(3) between the MLW and -20 ft MLW contours, and

(4) between the CCL and -20 ft MLW contours.

The CCL to MHW compartment represents the subaerial beach; the MHW to MLW compartment represents the intertidal beach; the MLW to -20 ft MLW compartment represents the subaqueous beach; and the CCL to -20 ft MLW compartment represents the entire beach where the majority of changes occur. Note that changes do occur in the beach profile at elevations less than -20 ft MLW during storms and other extreme events. Figure 9 presents a schematic illustration of the definition of beach volume in the present context. The subaerial beach is primarily affected by wind action, by elevated water levels and high waves during storms, and by swash processes. The intertidal beach is greatly affected by the persistent rise and fall of water level due to the tide and normal wave activity. Normal and extreme waves and water levels affect the subaqueous beach.

Figures 10 through 13 present beach volume changes on a profile-by-profile basis in the entire monitoring area for all comparison periods in the four vertical compartments. Figures 14 through 17 present the time-evolution of the total beach volume in the project area in the four vertical compartments. Detailed results for each beach profile are presented in Appendix F; significant findings in the project and the control areas are discussed next.



TAYLOR ENGINEERING INC.
9086 CYPRESS GREEN DRIVE
JACKSONVILLE, FLORIDA 32256

Figure 9 Schematic Definition of Beach Volumes

PROJECT	
REVISION	
SHEET	
DATE	

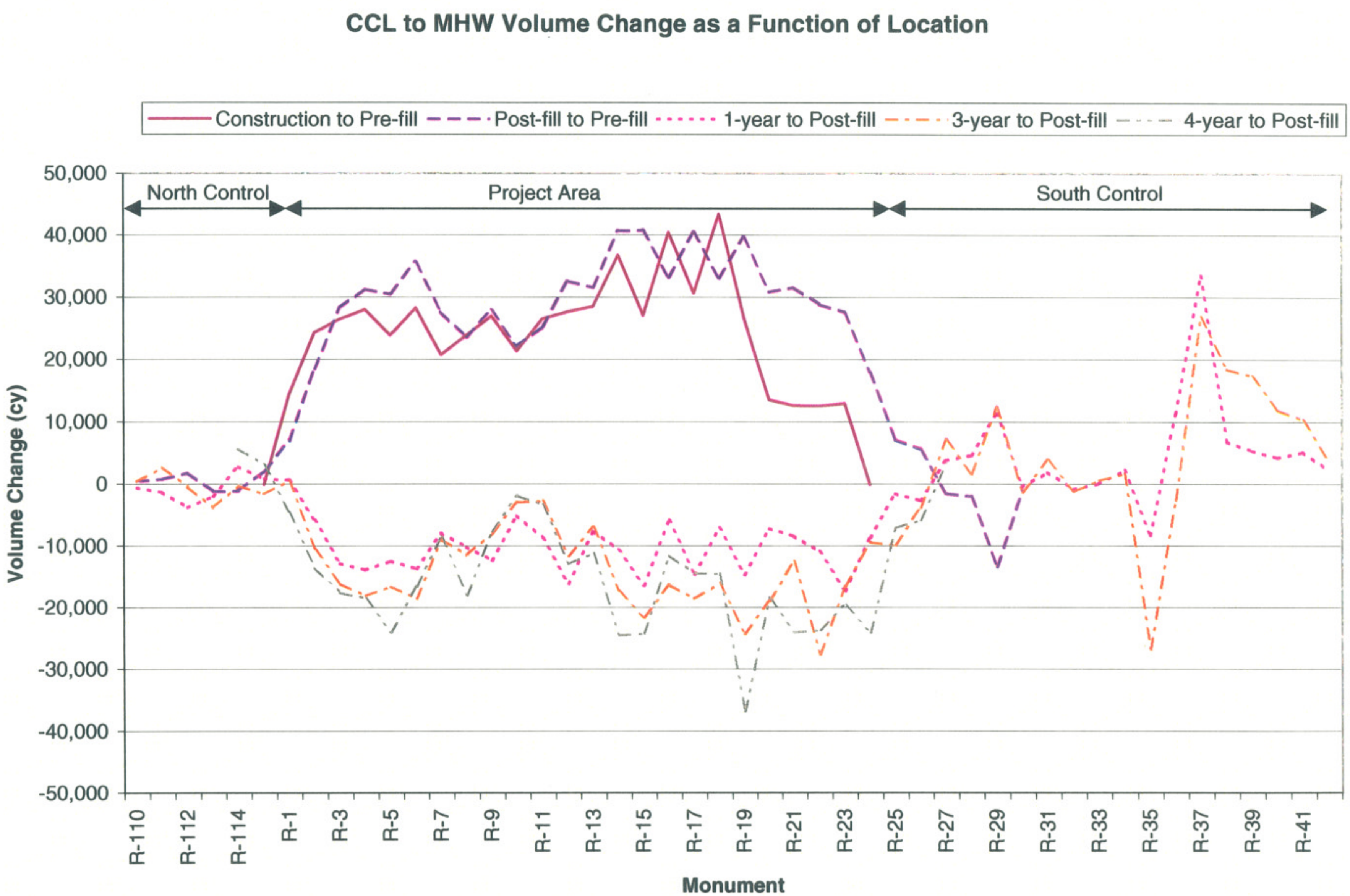


Figure 10 CCL to MHW Volume Change as a Function of Location

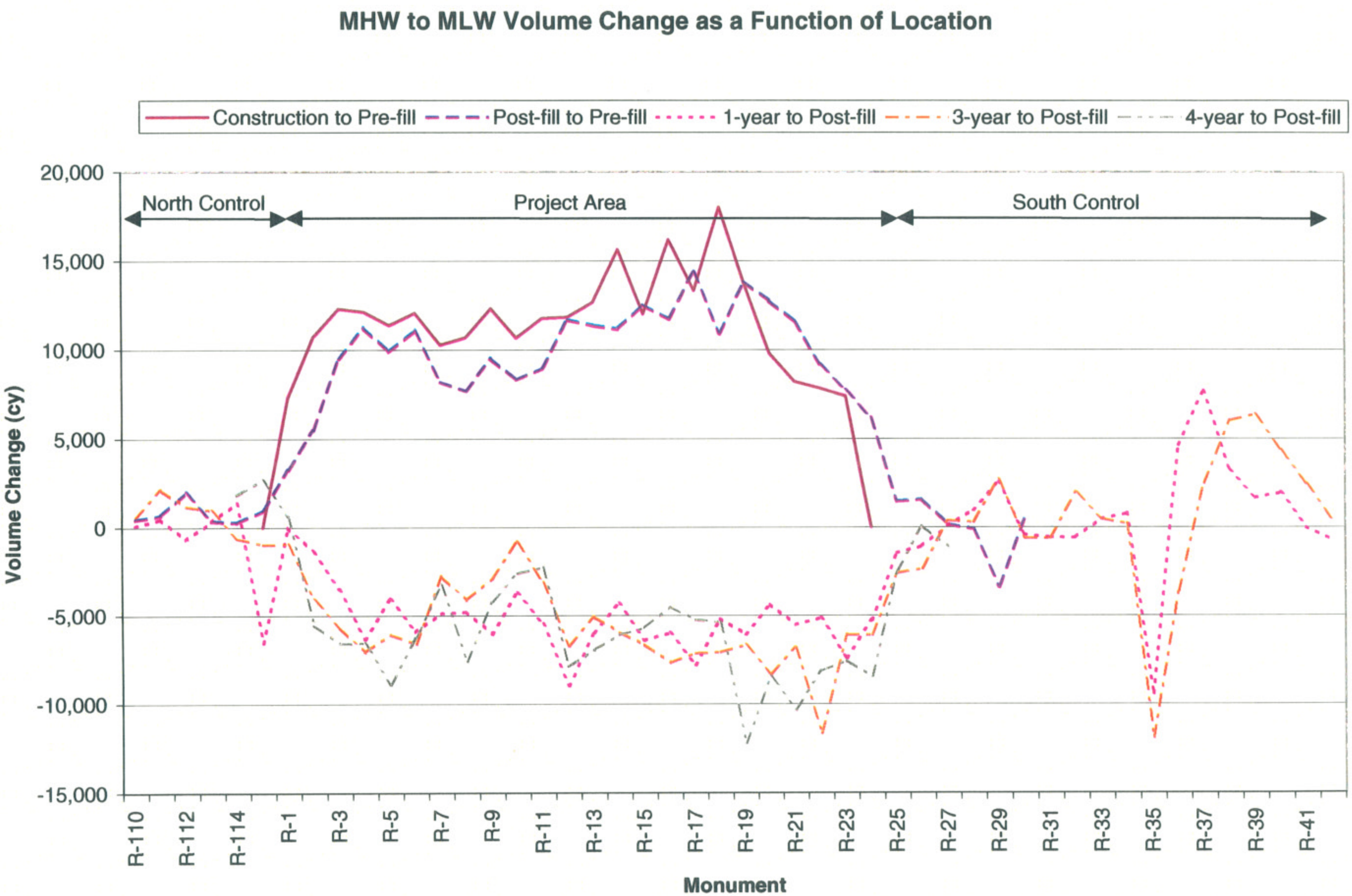


Figure 11 MHW to MLW Volume Change as a Function of Location

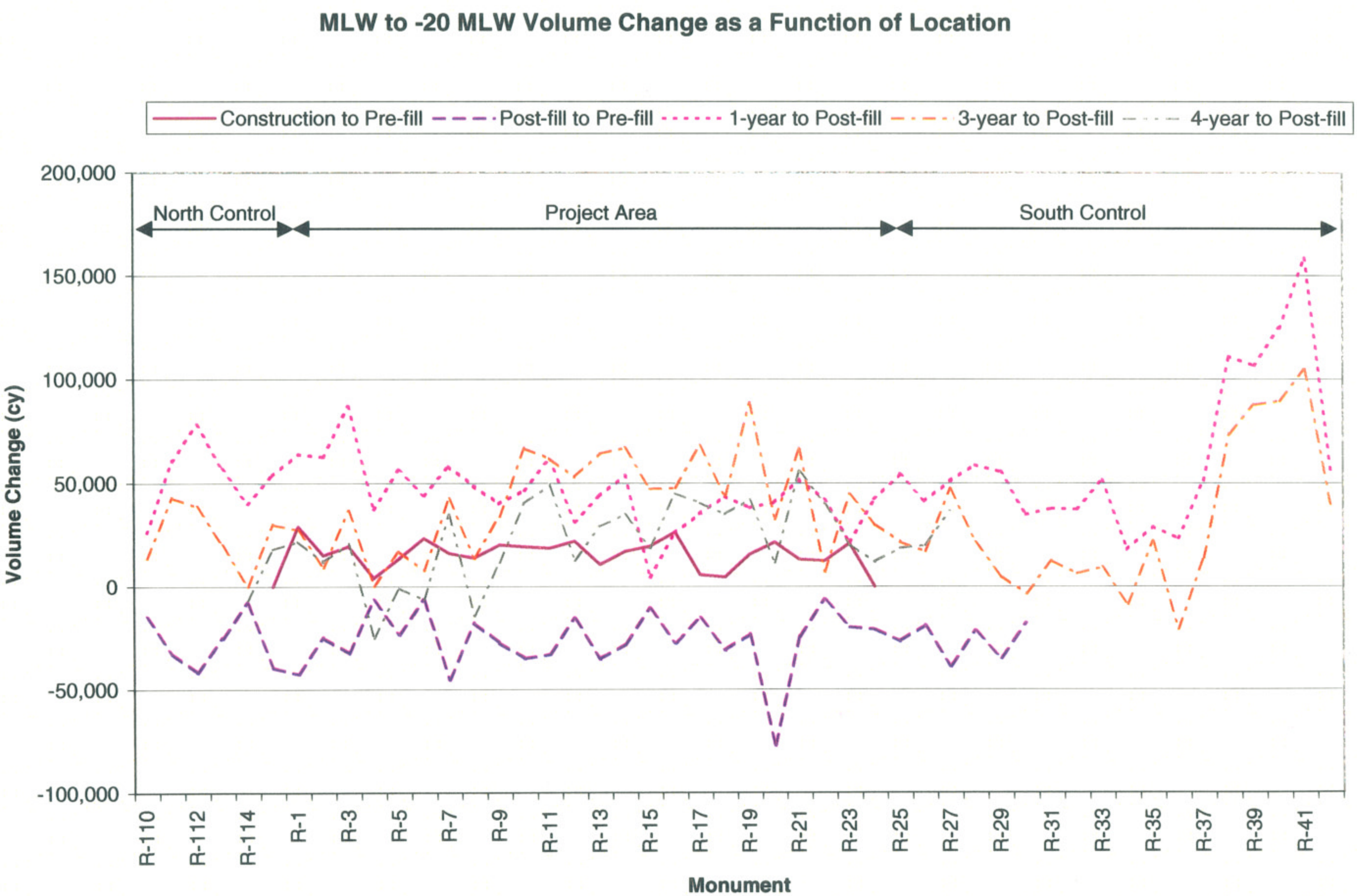


Figure 12 MLW to –20 MLW Volume Change as a Function of Location

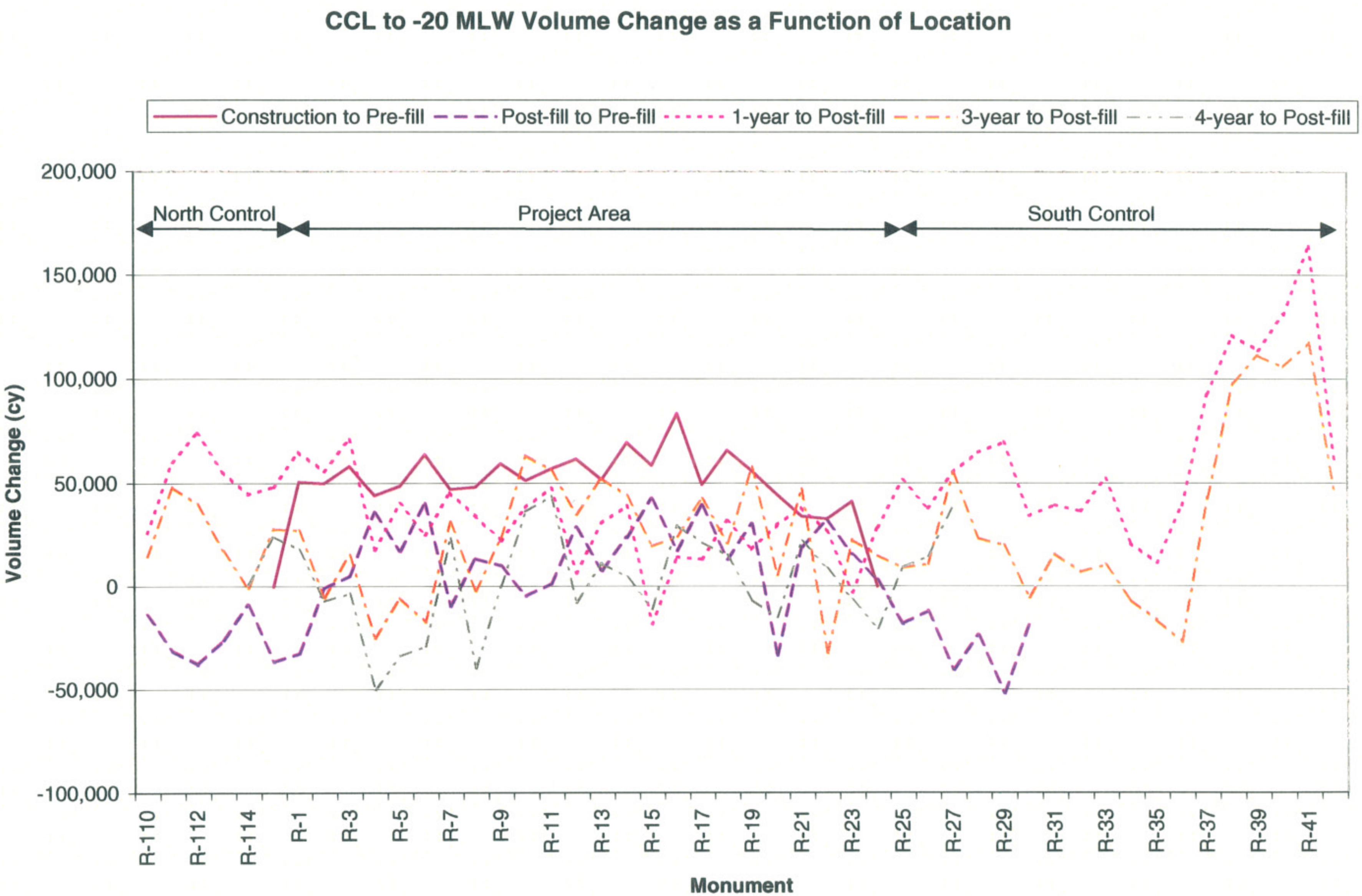


Figure 13 CCL to –20 MLW Volume Change as a Function of Location

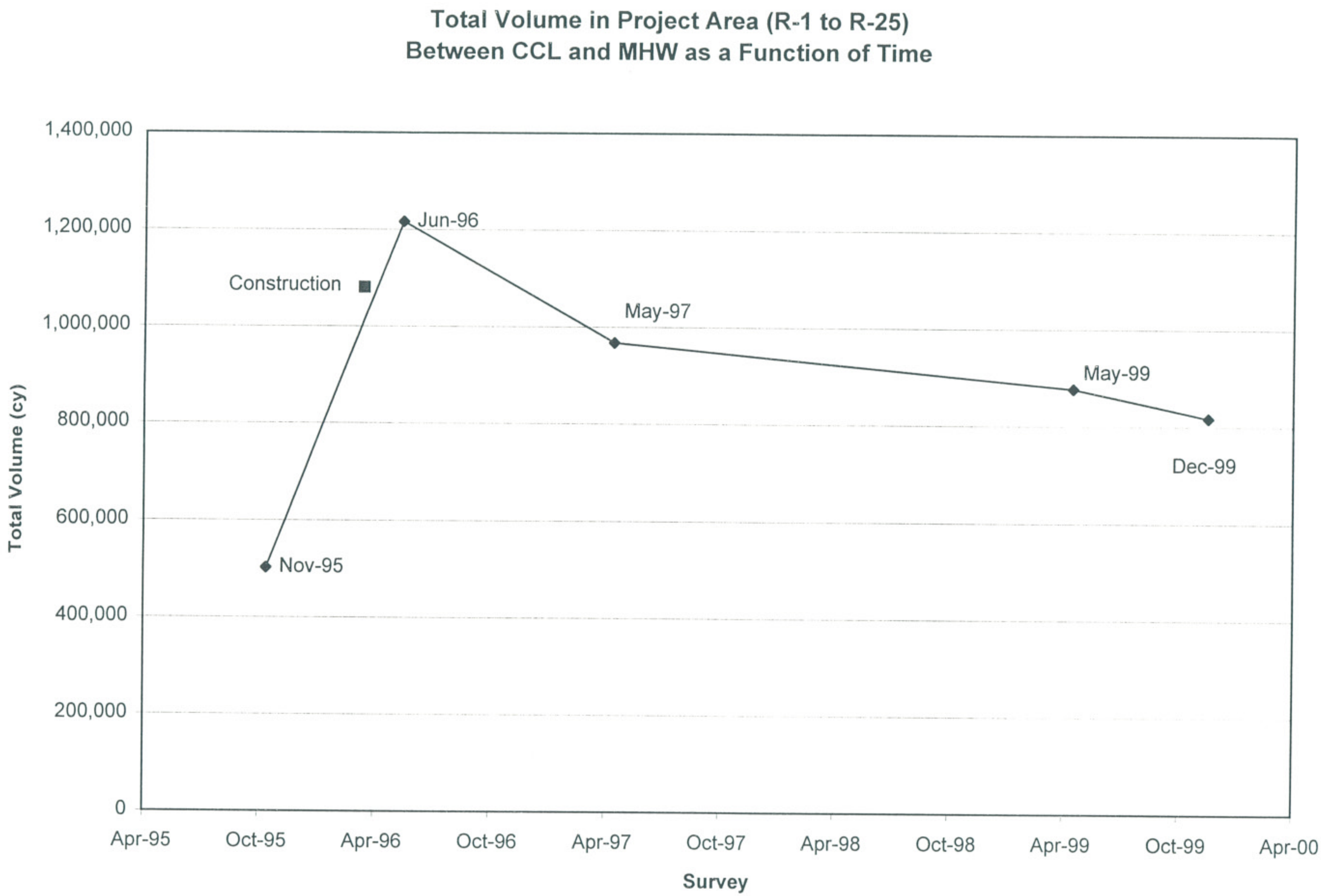


Figure 14 Total Volume in Project Area (R-1 to R-25) Between CCL and MHW as a Function of Time

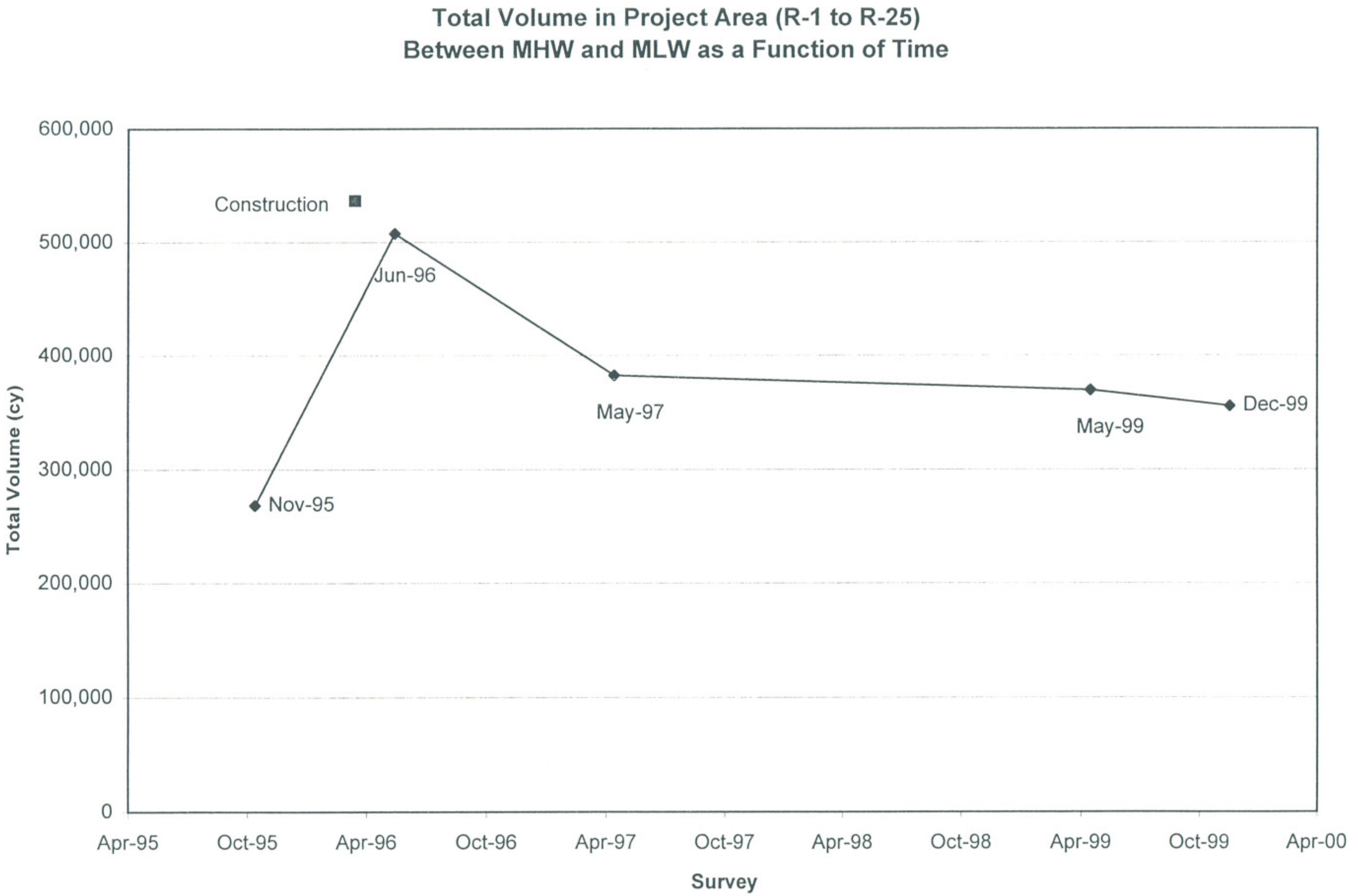


Figure 15 Total Volume in Project Area (R-1 to R-25) Between MHW and MLW as a Function of Time

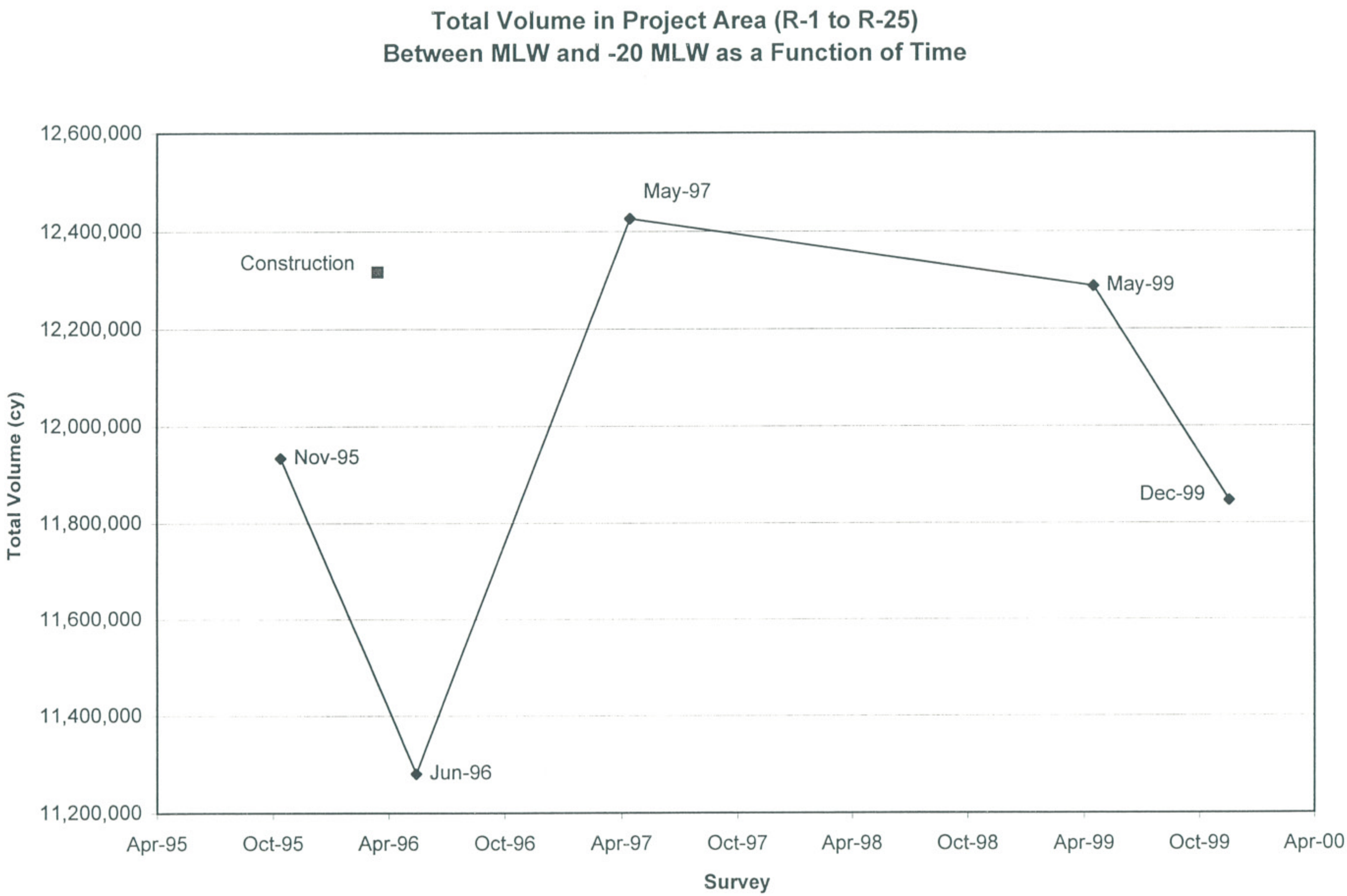


Figure 16 Total Volume in Project Area (R-1 to R-25) Between MLW and –20 MLW as a Function of Time

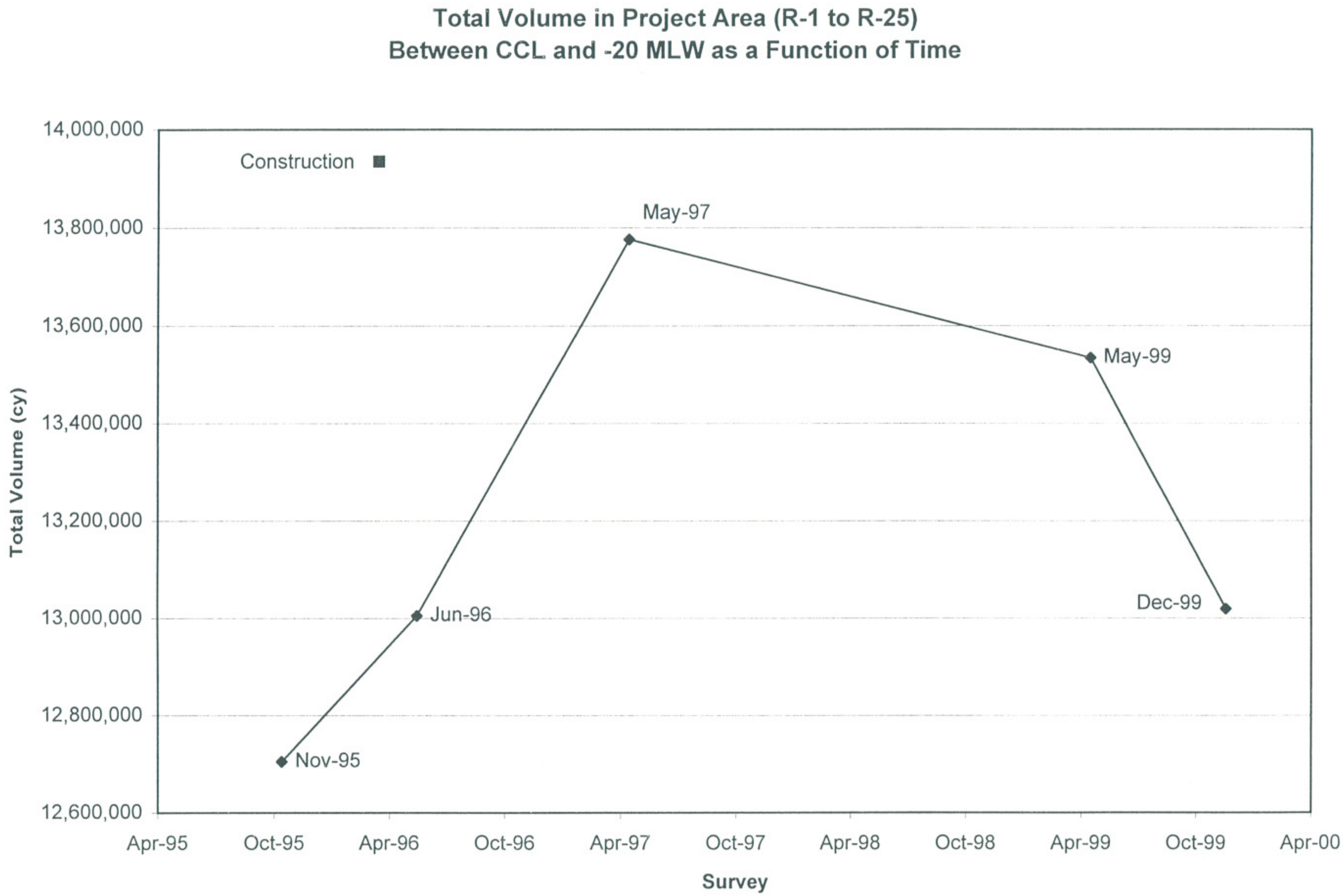


Figure 17 Total Volume in Project Area (R-1 to R-25) Between CCL and –20 MLW as a Function of Time

3.3.1 Project Area

A comparison of the post-fill (surveyed two months following project completion) and pre-fill beach volumes reveals that the project area gained approximately 714,000 cy of sand between the CCL and MHW contours and about 240,000 cy of sand between the MHW and MLW contours. The project area actually lost about 654,000 cy of sand between the MLW and -20 ft MLW contours. In total, the beach gained about 300,000 cy of sand between CCL and -20 ft MLW. An examination of constituent beach profiles indicates that the March northeaster which affected the project area during construction excavated a large offshore trench, typically between approximately -8 and -20 ft NGVD, just offshore the toe of the construction profile. Most of the sand excavated from this trench was lost offshore in depths in excess of 20 ft NGVD. Thus, given the vertical compartments over which volume changes were computed, the post-fill survey (taken approximately two months after project construction) is not an appropriate indicator of the volume of sand actually placed during the 1996 nourishment event. The specified construction template serves as a better indicator.

A comparison of the construction template and pre-fill beach volumes indicates that the beach gained approximately 578,000 cy of sand between CCL and MHW contours, about 268,000 cy of sand between the MHW and MLW contours, and about 383,000 cy of sand between the MLW and -20 ft MLW contours. In total, the beach gained about 1,230,000 cy of sand between the CCL and -20 ft MLW contours. Note that the effects of the March northeaster are factored out in this method of comparison; however, changes (erosion or accretion) in the beach between the pre-fill survey date (November 1995) and the actual construction date are not accounted for.

A comparison of 1-year and post-fill beach volumes indicates that the beach lost 249,000 cy of sand between the CCL and MHW contours, lost 125,000 cy of sand between the MHW and MLW contours, and gained 1,145,000 cy of sand between the MLW and -20 ft MLW contours. In total, the beach gained about 771,000 cy of sand between the CCL and -20 ft MLW contours.

The comparison of 1-year and construction template beach volumes indicates that the beach lost 113,000 cy of sand between the CCL and MHW contours, lost 154,000 cy of sand between the MHW and MLW contours, and gained 109,000 cy of sand between the MLW and –20 ft MLW contours. In total, the beach lost about 158,000 cy of sand between the CCL and –20 ft MLW contours, which about 13% of the total construction template volume.

A comparison of 3-year and post-fill beach volumes indicates that the project area lost 340,000 cy of sand between the CCL and MHW contours, lost 138,000 cy of sand between the MHW and MLW contours, and gained 1,007,000 cy of sand between the MLW and –20 ft MLW contours. In total, the beach gained about 529,000 cy of sand between the CCL and –20 ft MLW contours.

A comparison of 3-year and construction template beach volumes indicates that the project area lost 204,000 cy of sand between the CCL and MHW contours, lost 167,000 cy of sand between the MHW and MLW contours, and lost 29,000 cy of sand between the MLW and –20 ft MLW contours. In total, the beach lost about 400,000 cy of sand between the CCL and –20 ft MLW contours, which is about 33% of the total construction template volume.

A comparison of 4-year and post-fill beach volumes indicates that the project area lost 399,000 cy of sand between the CCL and MHW contours, lost 152,000 cy of sand between the MHW and MLW contours, and gained 566,000 cy of sand between the MLW and –20 ft MLW contours. In total, the beach gained about 14,000 cy of sand between the CCL and –20 ft MLW contours.

A comparison of 4-year and construction template beach volumes indicates that the project area lost 263,000 cy of sand between the CCL and MHW contours, lost 181,000 cy of sand between the MHW and MLW contours, and lost 471,000 cy of sand between the MLW and –20 ft MLW contours. In total, the beach lost about 916,000 cy of sand between the CCL and –20 ft MLW contours, which is about 75% of the total construction template volume.

3.3.2 North Control Area

A comparison of the post-fill (surveyed two months following project completion) and pre-fill beach volumes reveals that the north control area gained approximately 3,000 cy of sand between the CCL and MHW contours, gained about 5,000 cy of sand between the MHW and MLW contours, and lost 161,000 cy of sand between the MLW and –20 ft MLW contours. In total, the beach lost about 153,000 cy of sand between CCL and –20 ft MLW.

A comparison of 1-year and post-fill volumes indicates that the beach lost 3,000 cy of sand between the CCL and MHW contours, lost 5,000 cy of sand between the MHW and MLW contours, and gained 318,000 cy of sand between the MLW and –20 ft MLW contours. In total, the beach gained about 310,000 cy of sand between the CCL and –20 ft MLW contours.

A comparison of 3-year and post-fill volumes indicates that the beach lost 2,000 cy of sand between the CCL and MHW contours, gained 3,000 cy of sand between the MHW and MLW contours, and gained 147,000 cy of sand between the MLW and –20 ft MLW contours. In total, the beach gained about 148,000 cy of sand between the CCL and –20 ft MLW contours.

Results of the 4-year survey, covering only two profiles, cannot be directly compared with the above results that document overall changes for five profiles.

3.3.3 South Control Area

To enable consistent comparisons with results of the north control area (which encompasses five profiles), the following discussion only addresses the northern-most five profiles (R-26 through R-30) of the south control area. Volume changes computed for all the profiles (R26 through R-42) in the south control area are presented in Appendix F.

A comparison of the post-fill (surveyed two months following project completion) and pre-fill beach volumes reveals that the south control area lost approximately 12,000 cy of sand between the CCL and MHW contours, lost about 1,000 cy of sand between the MHW and MLW contours, and lost 132,000 cy of sand between the MLW and –20 ft MLW contours. In total, the beach lost about 145,000 cy of sand between CCL and –20 ft MLW.

A comparison of 1-year and post-fill volumes indicates that the beach gained 17,000 cy of sand between the CCL and MHW contours, gained 2,000 cy of sand between the MHW and MLW contours, and gained 243,000 cy of sand between the MLW and -20 ft MLW contours. In total, the beach gained about 262,000 cy of sand between the CCL and -20 ft MLW contours.

A comparison of 3-year and post-fill volumes indicates that the beach gained 16,000 cy of sand between the CCL and MHW contours, lost 500 cy of sand between the MHW and MLW contours, and gained 88,000 cy of sand between the MLW and -20 ft MLW contours. In total, the beach gained about 105,000 cy of sand between the CCL and -20 ft MLW contours.

Results of the 4-year survey, covering only two profiles, cannot be directly compared with the above results that document overall changes for five profiles.

4.0 BORROW AREA VOLUME ANALYSIS

Figures G1 through G4 in Appendix G illustrate the borrow area bathymetry for each of the surveys listed in Table 3 (Chapter 2). Table 7 shows the volume changes calculated between surveys. The survey comparisons include post-fill to pre-fill, 3-year to post-fill, and 4-year to post-fill. Figures G5 through G7 in Appendix G illustrate the borrow area contour changes for the survey comparisons listed in Table 7. As seen in Table 7, approximately 1.7 Mcy of sand were dredged from the borrow area for the 1996 project (post-fill to pre-fill comparison). By the 3-year survey, the borrow area accreted 180,000 cy of sand, and by the 4-year survey, accreted 270,000 cy. Although the USACE did conduct borrow area surveys at one year and three years, these surveys contain errors that prevent them from being useful in this analysis.

Table 7

Borrow Area Volume Change

Volume Change Between Surveys	Volume Change (Cubic Yards)
Post-fill, June 1996 - Pre-fill, Nov 1995	-1,727,873
3-year, May 1999 - Post-fill, June 1996	182,881
4-year, April 2000 - Post-fill, June 1996	272,154

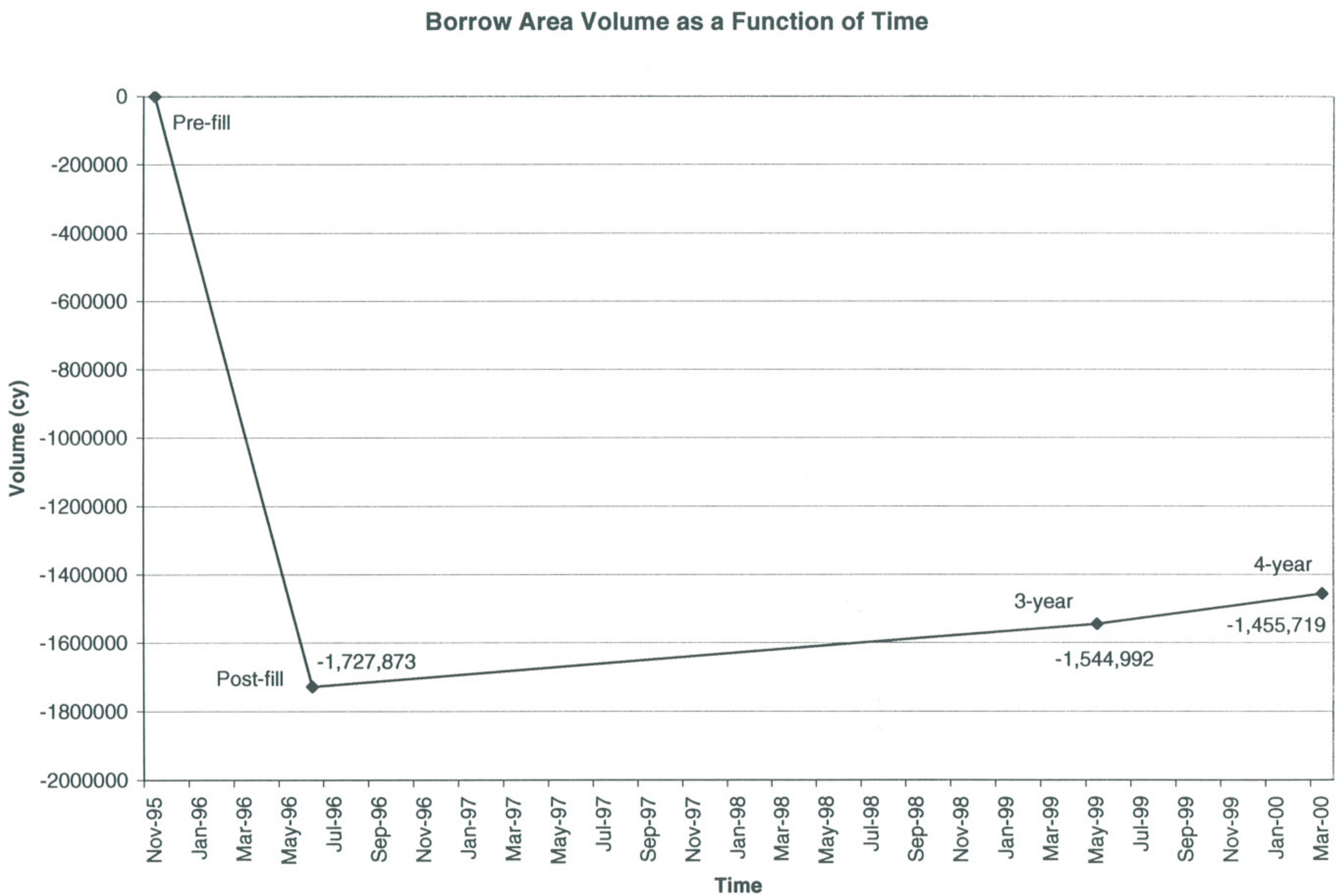


Figure 18 Borrow Area Volume as a Function of Time

5.0 STORM IMPACT

5.1 March 1996 Northeaster

Between March 11-13, 1996 a severe northeaster impacted the beach nourishment project during its construction. Construction of the project began at profile R-22 and proceeded north and south. Approximately three-quarters of the project, from profile R-7 to profile R-25, were complete when the northeaster impacted the project area (Cynthia Perez, USACE — personal communication). National Oceanic and Atmospheric Administration (NOAA) offshore buoy #41009 (28.50 °N, 80.18 °W), located offshore the project area, recorded a peak significant wave height of 22.5 ft and a peak average wave period of 10 s (www.ndbc.noaa.gov). Table H1 in Appendix H lists the significant wave heights and average wave periods recorded by NOAA buoy 41009 between March 9-15, 1996. Figure H1 illustrates the significant wave height and average wave period during that time period. At the project area, breaking wave heights were between approximately 12 and 15 ft. At profile R-23, storm water levels overtopped the newly constructed dune (elevation 12.5 ft NGVD) (Cynthia Perez, USACE — personal communication).

Immediately after the March northeaster, the contractor completed construction of the project between profiles R-1 and R-7. As he pulled up pipeline, he restored some of the previously constructed area of the project affected by the storm between profiles R-20 and R-25. The volume replaced was about 70,000 cy of sand on the dry beach (Rick McMillen, USACE — personal communication).

As seen from the beach profile plots in Appendix C, the post-fill survey is considerably eroded from the pre-fill survey between approximately –8 ft and –20 ft NGVD. Above –8 ft NGVD, the beach profile didn't experience any storm erosion because of the construction of the project. It was estimated that the portion of the beach project, which was complete at the time of the northeaster, prevented approximately $17.8 million in storm damages (USACE).

5.2 Winter 1996 Northeasters

In the winter of 1996, two fairly significant northeaster storms impacted the project area. These storms occurred between October 4-8 and November 15-18, 1996. For the October northeaster, the peak significant wave height was 16.4 ft and the peak average wave period was 8 s. The peak significant wave height was 16.5 ft and the peak average wave period was 10 s for the November northeaster. Tables H2 and H3 list the significant wave heights and average wave periods between October 2-8 and November

13-19, 1996 recorded by NOAA buoy 41009. Figures H2 and H3 illustrate the significant wave height and average wave period during the storm events.

5.3 Winter 1998 Northeaster

The next significant storm to impact the project area was a northeaster between February 2-6, 1998. For this northeaster, the peak significant wave height was 16.6 ft and the peak average wave period was 8 s. Table H4 lists the significant wave heights and average wave periods recorded by NOAA buoy 41009 between January 31-February 6, 1998, and Figure H4 illustrates these parameters during that time period.

5.4 Fall 1999 Hurricanes

In the fall of 1999, three hurricanes impacted the project area. Hurricane Dennis occurred between August 28-31, Hurricane Floyd occurred between September 14-16, and Hurricane Irene occurred between October 15-17. Hurricane Dennis was classified as a Category 2 hurricane, Hurricane Irene was classified as a Category 1 hurricane, and Hurricane Floyd was classified a Category 4 hurricane when closest to the project area. Tables H5 through H7 list the significant wave heights and average wave periods recorded between August 26-September 1 (Hurricane Dennis), September 12-18 (Hurricane Floyd), and October 13-19, 1999 (Hurricane Irene). Figures H5 through H7 illustrate the significant wave height and average wave period, recorded by NOAA buoy 41009, during these events. During Hurricane Dennis, the peak significant wave height was 16.1 ft and the peak average wave period was 12 s. During Hurricane Floyd, the peak significant wave height and peak average wave period were 32 ft and 9s. During Hurricane Irene, the peak significant wave height was 23 ft and the peak average wave period was 8 s.

6.0 SUMMARY AND CONCLUSIONS

The first nourishment of the Martin County Shore Protection Project, extending approximately four miles from FDEP profile R-1 to profile R-25, was completed in April 1996 with the placement of approximately 1,340,000 cy of sand. The borrow site for the project was Gilbert Shoal, located about 1.2 miles offshore the southern region of the project.

This study analyzed all beach profile surveys to document the impacts of the beach nourishment event on the project and control areas. The construction template specified by the USACE was also used in analysis. All beach profiles were plotted (Appendixes C and D) to document profile shape evolution and qualitatively assess changes in positions of key contours. All beach profiles from the pre-, post-, 1-year, 2-year, and 4-year surveys were analyzed to document MHW and MLW positions and changes (Section 3.2; Appendix E). The predictions of an analytical model simulating shoreline evolution were compared to observed shoreline behavior (Section 3.2.4). The pre-, post-, 1-year, 3-year, and 4-year surveys were also analyzed to document beach volumes and changes in four distinct compartments representing the subaerial (CCL to MHW), the intertidal (MHW to MLW), the subaqueous (MLW to -20 ft MLW), and the total active (CCL to -20 ft MLW) beach (Section 3.3; Appendix F).

This study analyzed the pre-, post-, 3-year and 4-year borrow site bathymetric surveys to document the impacts of excavation on the borrow site bathymetry. The 1-year and 2-year post-fill borrow site surveys were excluded from analysis because of problems with data quality. Digital terrain modeling was used to plot borrow site bathymetries and bathymetric changes over various comparison periods (Appendix G) and to compute volume changes (Section 4.0).

6.1 Shoreline Positions

6.1.1 Project Area

Comparing the post- and pre-fill surveys, the MHW and MLW shorelines, on average, advanced 105 ft and 94 ft following project construction. Consistent with theory, the project area eroded quickly in the first year and then the rate of erosion slowed but persisted through four years. One year following construction, the MHW and MLW shorelines had retreated 54 ft and 51 ft, on average, from their post-fill locations. By the time of the 4-year survey, the MHW and MLW shorelines, on average, had retreated 65 ft and 61 ft from their post-fill positions. Though the shorelines have retreated fairly uniformly over time, four years after project construction, the MHW and MLW shorelines are still advanced from their pre-fill locations.

6.1.2 North Control Area

Comparing the post- and pre-fill surveys, the MHW and MLW shorelines, on average, advanced 7 ft and 12 ft following project construction with all profiles experiencing advances. Individual and average shorelines in this area experienced both advance and retreat over the following years. By the time of the 4-year survey, the MHW and MLW shorelines, on average, had advanced 19 ft and 23 ft from their post-fill positions.

Beach fill evolution theory suggests that the north control area should benefit from the nourishment project by accreting sand dispersed longshore from the beach fill placement area. However, in the present project, the impacts of multiple storms have caused portions of the subaerial beach fill to move offshore to fill up the nearshore trench evident in the post-construction survey. Consequently, the purely longshore dispersion process of the fill placement area appears to have been diluted enough that the north control area did not receive the expected benefit. Note that this discussion only pertains to a discrete (shoreline) contour; the total effect of beach fill dispersion on adjacent beaches must be examined in terms of beach volumes, discussed in Section 6.2.2.

6.1.3 South Control Area

To enable consistent comparisons with results of the north control area (which encompasses five profiles), the following discussion only addresses the northern-most five profiles (R-26 through R-30) of the south control area.

Comparing the post- and pre-fill surveys, on average, the MHW advanced 1 ft while the MLW shoreline retreated 9 ft following project construction. Individual profiles experienced both advance and retreat during this interval and over the following years. By the time of the 4-year survey, the MHW and MLW shorelines, on average, had retreated 12 ft and 4 ft from their post-fill positions.

Again, beach fill evolution theory suggests that the south control area should benefit from the nourishment project by accreting sand dispersed longshore from the beach fill placement area. However, in the present project, the impacts of multiple storms have caused portions of the subaerial beach fill to move offshore to fill up the nearshore trench evident in the post-construction survey. Consequently, the purely longshore dispersion process of the fill placement area appears to have been diluted enough that the south control area did not receive the expected benefit. The presence of continuous band of hardbottom in the nearshore off the south control area might have some bearing on local shoreline behavior; rigorously quantifying its effects is beyond the scope of the present study. Note that this discussion only pertains to a discrete (shoreline) contour; the total effect of beach fill dispersion on adjacent beaches must be examined in terms of beach volumes, discussed in Section 6.2.3.

6.2 Beach Volumes

6.2.1 Project Area

Comparison of the post-fill (surveyed two months following project construction) and the pre-fill beach conditions suggests that beach gained 714,000 cy of sand between the CCL and MHW contours, gained 240,000 cy of sand between the MHW and MLW contours, lost 654,000 cy of sand between the MLW and -20 ft MLW contours, and gained 300,000 cy of sand between the CCL and -20 ft MLW contours. These volumes sharply contrast with the project pay volume — pay surveys indicate that the contractor placed approximately 1,340,000 cy of sand on the beach. The reason for the discrepancy is the impact of a March northeaster that affected the project area during construction.

The severe northeaster impacted the project area between March 11 and March 13, 1996, during the construction of the beach fill. The project had progressed between R-25 and R-7 before the March northeaster (ATM, 1998). Anecdotal accounts suggest that the storm caused serious erosion. After the storm, the contractor completed the project and also replaced some sand in the vicinity of R-20 through R-25. The post-fill survey, taken approximately three months after the storm, reflects storm impacts and the contractor's mitigation. This storm excavated a massive trench at elevations between -8 and -20 ft NGVD. Sand eroded from the trench was typically transported offshore the -20 ft contour. Given the massive erosion that resulted, the post-fill survey severely underestimates the 1996 sand placement volume. The timing of the northeaster and the lack of immediate pre- and post-storm surveys diminish the value of the June 1996 survey as a true indicator of the volume of sand placed during the 1996 beach nourishment. Rather, the construction fill template serves as a better proxy to represent immediate post-fill conditions.

Comparison of the construction fill template and the pre-fill beach conditions suggests that beach gained 578,000 cy of sand between the CCL and MHW contours, gained 268,000 cy of sand between the MHW and MLW contours, gained 383,000 cy of sand between the MLW and -20 ft MLW contours, and gained 1,230,000 cy of sand between the CCL and -20 ft MLW contours. These volumes are more reasonable; the total volume compares favorably with the pay volume (1,340,000cy). These volumes also indicate that the March 1996 northeaster caused about 106,000 cy of accretion above MLW and about 1,037,000 cy of erosion below MLW. Thus, the beach profiles of the post-fill survey above MLW are fairly representative of the constructed profile; however, the beach profiles of the post-fill survey below MLW are not truly representative of the constructed profile.

Between June 1996 and May 1997, the beach eroded above MLW and accreted below MLW. The subaerial and intertidal beach compartments eroded a total of 374,000 cy while the subaqueous compartment accreted 1,145,000 cy in the one year following construction. Thus, the subaqueous compartment gained back all the sand eroded by the March 1996 northeaster and actually accreted about 108,000 cy compared to the construction template condition. The project area lost 13% of the total construction template volume by May 1997.

Between May 1997 and May 1999, the beach eroded along all compartments. The subaerial, intertidal, and subaerial beach compartment eroded about 91,000 cy, 13,000 cy, and 138,000 cy; the total beach eroded about 242,000 cy. By May 1999, the project area lost 33% of the total construction template volume.

Between May 1999 and December 1999, the beach eroded heavily in all compartments. The subaerial, intertidal, and subaerial beach compartment eroded about 59,000, 14,000, and 442,000 cy; the total beach eroded about 515,000 cy. Most of the erosion was probably episodic and caused by Hurricanes Dennis, Floyd, and Irene, which affected the project area between August and October 1999.

Comparing the 4-year and construction template beach volumes, the subaerial beach has lost 263,000 cy, the intertidal beach has lost 181,000 cy, and the subaqueous beach has lost 471,000 cy. The total beach has lost 916,000 cy of sand, which is about 75% of the total quantity of sand placed on the beach during the 1996 nourishment. The USACE (1993) computed a renourishment interval of 11 years. Note that the renourishment interval, assuming a constant erosion rate in the project area, is derived from economic considerations by minimizing the average annual equivalent cost of project maintenance. The USACE (1993), analyzing historical beach behavior, developed an annual erosion rate of 53,600 cy/year for 3.75 miles (R-1 to R-23) of the project area. This rate is equivalent to a background erosion rate of 57,200 cy/yr over the 4-mile project length. Using this historical background erosion rate and not accounting for additional erosion due to dispersion processes (which is not documented in USACE, 1993), the beach nourishment project would be expected to erode about 200,000 cy in the placement area. In contrast, the project has eroded about 916,000 cy, which is about 4.6 times the historical background erosion rate. With these sand volume losses, the beach requires renourishment well before the original 11-year estimate.

The high sand loss rate can be attributed to (a) the impacts of the March 1996 northeaster and the series of hurricanes in 1999, and (b) the normal dispersion of the beach fill. Other factors possibly influencing beach fill evolution might be sand quality (the borrow sand was coarser and had higher carbonate content than native sand) and beach compaction (the beach fill was tilled between R-1 and R-14 and left untilled between R-15 and R-25 – Ecological Associates, Inc., 1999). Coarse sand is typically expected to perform better than fine sand; however, the size, erosional and depositional characteristics of carbonate sands are possibly distinct from those of silica sand. The effects of these characteristics on beach fill performance are presently unknown; future beach fill designs should attempt to better quantify their impacts on performance.

6.2.2 North Control Area

Comparison of the post-fill (surveyed two months following project construction) and the pre-fill beach conditions suggests that the beach gained 8,000 cy of sand above MLW and lost 161,000 cy of sand below MLW; the total beach lost 153,000 cy of sand between the CCL and -20 ft MLW contours. The trends of these volume changes are consistent with those for the project area for the corresponding comparison (post- to pre-fill). Again, the March 1996 northeaster eroded sand off the subaerial portions of the beach.

Between June 1996 (post-fill) and May 1997 (1-year), the beach eroded above MLW and accreted below MLW. The subaerial and intertidal beach compartments eroded a total of 8,000 cy while the subaqueous compartment accreted 318,000 cy in the one year following construction.

Between May 1997 (1-year) and May 1999 (3-year), the beach accreted above MLW and eroded below MLW. The subaerial and intertidal beach compartments accreted a total of 8,800 cy, while the subaqueous beach compartment eroded about 171,000 cy; the total beach eroded about 162,000 cy.

Thus, in the three years following construction, the north control area gained a total of about 150,000 cy of sand. Changes in the north control area are dominated by those changes occurring in the subaerial compartment, that is, most of the sand accreted offshore. The trends of overall beach change across all contours, established by beach volume computations, are consistent with those observed for shoreline (a discrete contour) changes.

6.2.3 South Control Area

To enable consistent comparisons with results of the north control area (which encompasses five profiles), the following discussion only addresses the northern-most five profiles (R-26 through R-30) of the south control area.

Comparison of the post-fill (surveyed two months following project construction) and the pre-fill beach conditions suggest that the beach eroded in all compartments: it eroded 13,000 cy of sand above MLW and it eroded 132,000 cy of sand below MLW. The total beach eroded 145,000 cy of sand between the CCL and -20 ft MLW contours. The March 1996 northeaster eroded sand off the subaqueous, the intertidal, and the subaerial portions of the beach.

Between June 1996 (post-fill) and May 1997 (1-year), the beach accreted in all compartments. The subaerial and intertidal beach compartments accreted a total of 19,000 cy, while the subaqueous compartment accreted 243,000 cy in the one year following construction. The total beach, between CCL and -20 ft MLW, accreted 264,000 cy.

Between May 1997 (1-year) and May 1999 (3-year), the beach eroded in all compartments. The subaerial and intertidal beach compartments eroded about 2,500 cy and the subaqueous compartment eroded about 155,000 cy. The total beach, between CCL and -20 ft MLW, eroded about 157,000 cy.

Thus, in the three years following construction, the south control area gained a total of about 100,000 cy of sand. Changes in the south control area beach are dominated by those changes occurring in the subaerial compartment, that is, most of the sand accreted offshore. These trends are consistent with that observed for the north control area. However, unlike those observed in the north control area, the trends of overall beach change across all contours, established by beach volume computations, are opposite that observed for shoreline (a discrete contour) changes.

6.3 Borrow Site

Approximately 1,700,000 cy of sand were dredged from the borrow area for the 1996 project (post-fill to pre-fill comparison). The borrow area has since been filling up steadily – by the 3-year survey, the borrow area accreted 180,000 cy of sand, and by the 4-year survey, it accreted 270,000 cy of sand. This translates into an infilling rate of about 77,000 cy/yr. The causes for borrow site infilling would include (1) offshore-directed cross shore transport of sand from the beach and dune system, (2) onshore-directed cross shore transport due to tide- and wave-related currents, and (3) to a lesser extent, longshore transport of sand due to wave-driven currents.

7.0 REFERENCES

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